THE EUROPEAN WASP
(*Vespula Germanica Fab.*)
IN NEW ZEALAND

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THE EUROPEAN WASP
(*Vespula germanica* Fab.)
IN NEW ZEALAND

by

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Auckland

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Inset 1

The European Wasp
(*Vespula germanica* Fab.)
in New Zealand

INTRODUCTION

This paper is an account of work carried out on the European wasp, *Vespula germanica* Fab., from 1949 to 1952. As all hope of eradication had disappeared at the time the work was begun, the purpose of the investigation was to study the progress of the infestation with special reference to economic aspects and to possibilities of control. It must be emphasised that because most of the work was carried out in the Waikato district many of the observations, as for example on seasonal cycles, refer only to that area.

THE COLONISATION OF NEW ZEALAND BY *Vespula germanica*

THE INITIAL OUTBREAK IN NEW ZEALAND

The genus *Vespula* (*Vespa*) was first recorded in New Zealand by Thomson (1922), a record based on live wasps from the Wairarapa, identified by officers of the Department of Agriculture as *Vespa germanica* Fab.

The species did not become established, and it was not observed again until April 1945 at Te Rapa, Hamilton, where seven nests of *Vespula germanica* were discovered. Presumably the second introduction was just prior to the summer of 1944. It is likely that hibernating queens were introduced into New Zealand from Europe in cases containing aeroplane parts which were stored at the Te Rapa Air Force Depot.

On 27 April 1945 two drones and one worker of *Vespula vulgaris* L. were taken by Mr Wainwright at Mechanic's Bay, Auckland. These specimens are now in the insect collection of the Plant Diseases Division. An embryo nest, complete with queen, of *V. vulgaris* was taken on 7 November 1945 at Takapuna, Auckland. No further specimens of *V. vulgaris* have been taken in the field, and presumably the species has failed to become established.

Mr J. Bequaert, Museum of Comparative Zoology, Massachusetts, U.S.A., suggests (in letter) that the cause of the apparent failure of *V.*

vulgaris to become established may be climatic. He states that, "In Europe and North America *V. vulgaris* is somewhat more northern and prefers cooler areas, e.g., in the mountains. *V. germanica* thrives better in warmer areas and it is the only one of the two which occurs in North-Western Africa (Algeria, etc.). Possibly the climate around Auckland is too warm for *V. vulgaris*. In this connection it will be of interest to see how far south *V. germanica* will spread in New Zealand."

Laidlaw (1934) claims that *V. germanica* is susceptible to low temperature and high humidity and cannot flourish where either of these is present in excess, as for example in moorland country.

SUBSEQUENT DEVELOPMENT OF THE INFESTATION

Data on the limits of the infested areas since 1945 have been compiled from records of the Department of Agriculture and local bodies; some indication of the measure of infestation is given by the amount of DDT powder issued for wasp control.

Totals of nests destroyed are only those actually reported to the Department of Agriculture and local bodies, and do not include many unnotified nests destroyed by individuals. Consequently the limits of the infested area in the different years are only approximate. Table 1 shows the number of reported nests and their density per square mile of the infested area.

TABLE 1—NUMBER OF NESTS OF *Vespula germanica* REPORTED IN THE YEARS 1945–51 INCLUSIVE AND THEIR DENSITY PER SQUARE MILE OF INFESTED AREA

Year	Approximate Infested Area (sq. m.)	Number of Nests Reported	Nests per sq. m.	Number of Nests as % of Those Found in Previous Year
1945	15	7	0·47	..
1946	615	142	0·23	2,030
1947	1,465	387	0·26	272
1948	6,365	2,000	0·31	517
1949	21,165	5,758	0·27	288
1950	22,265	4,485	0·20	78
1951	31,565	6,048	0·19	135

Table 1 shows that 1948 was a year of marked abundance. Observations confirmed this, especially in the Central Waikato.

In subsequent years there was a marked reduction in density, and, compared with past seasons, wasps were scarce in 1950 and 1951, especially in those areas that had been colonised initially.

In addition, localised outbreaks occurred in newly colonised areas as follows:

1950 Taupo, Rotorua, Whakatane, Tauranga, Waihi, Thames, and Te Aroha.
1951 Raglan, Te Kuiti, Taumarunui, and Tauranga.

The distribution of *V. germanica* in New Zealand in the years 1945–51 inclusive is shown in fig. 1.

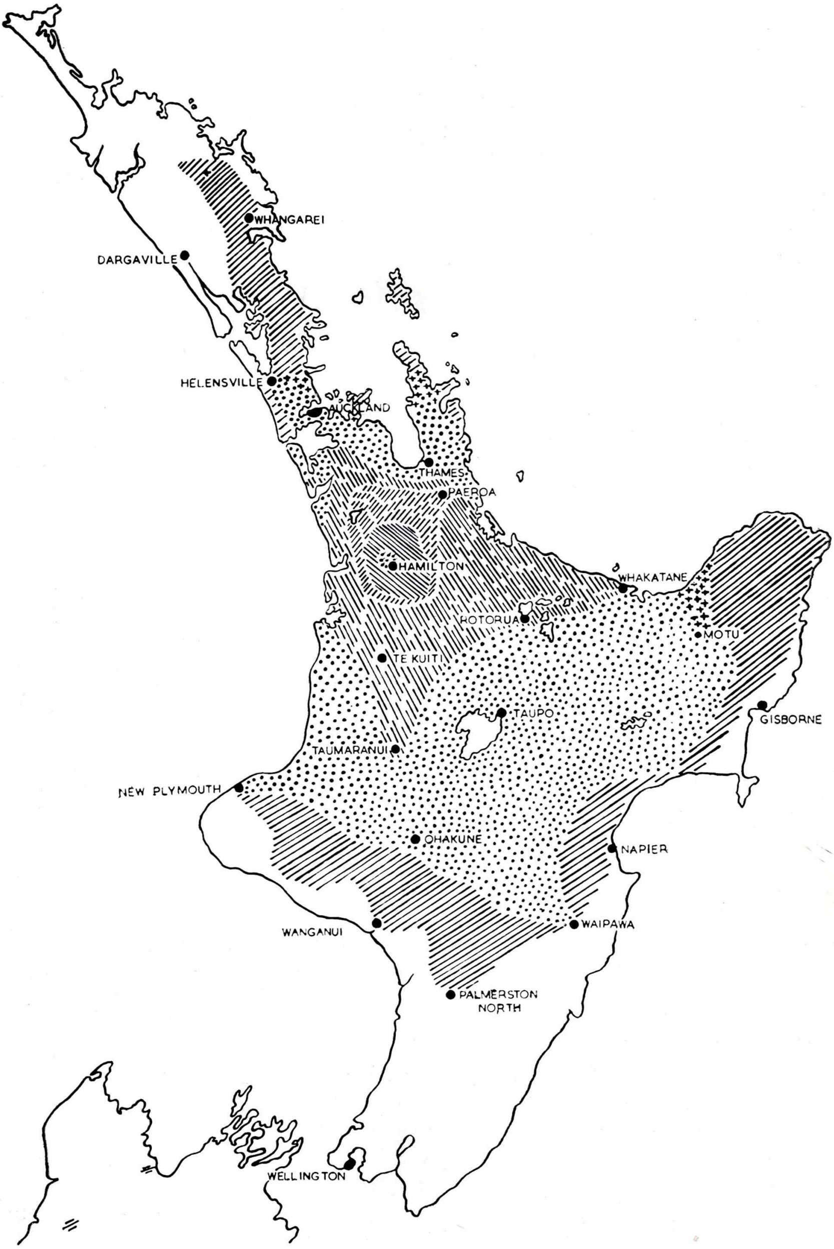


Fig. 1—The distribution of *Vespula germanica* in New Zealand in the years 1945–51

Inset 2

DISPERSAL

Although queen wasps are exceptionally strong fliers, observations have shown that mated queens rarely fly more than 1,000 yards from their nest of origin before establishing nests. Consequently, as they are little affected by winds, even of high velocity, the spread of the pest by natural means is comparatively slow.

Rail traffic, and to a lesser extent motor traffic, are undoubtedly the main agencies by which queen wasps have become dispersed over the greater part of the North Island of New Zealand. In this respect the two

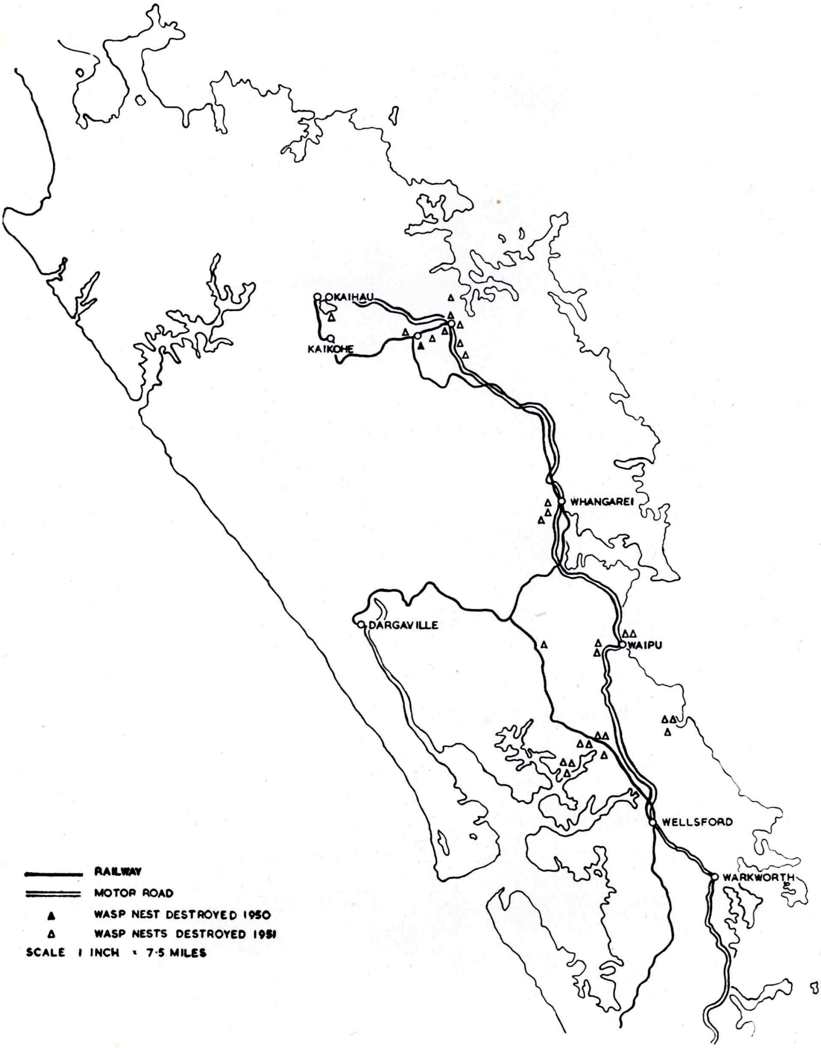


Fig. 2—The distribution of *V. germanica* in North Auckland (1950–51) salients, one to Paeroa and the other to Taumarunui in 1947 and 1948 respectively (fig. 1), are rather significant.

Fig. 2 shows the proximity of wasp nests to communication routes in North Auckland in the years 1950 and 1951. Prior to the winter of 1951 these nests were the only ones reported north of Warkworth.

Thus the absence of wasps from localised areas may often be attributed to poor communications reducing the chances of dispersal by rail or motor traffic.

AN INFESTATION AT MIDDLEMORE, AUCKLAND

In May 1948 a nest of *V. germanica*, from which young queens had already flown, was found on the links of the Auckland Golf Club, Middlemore.

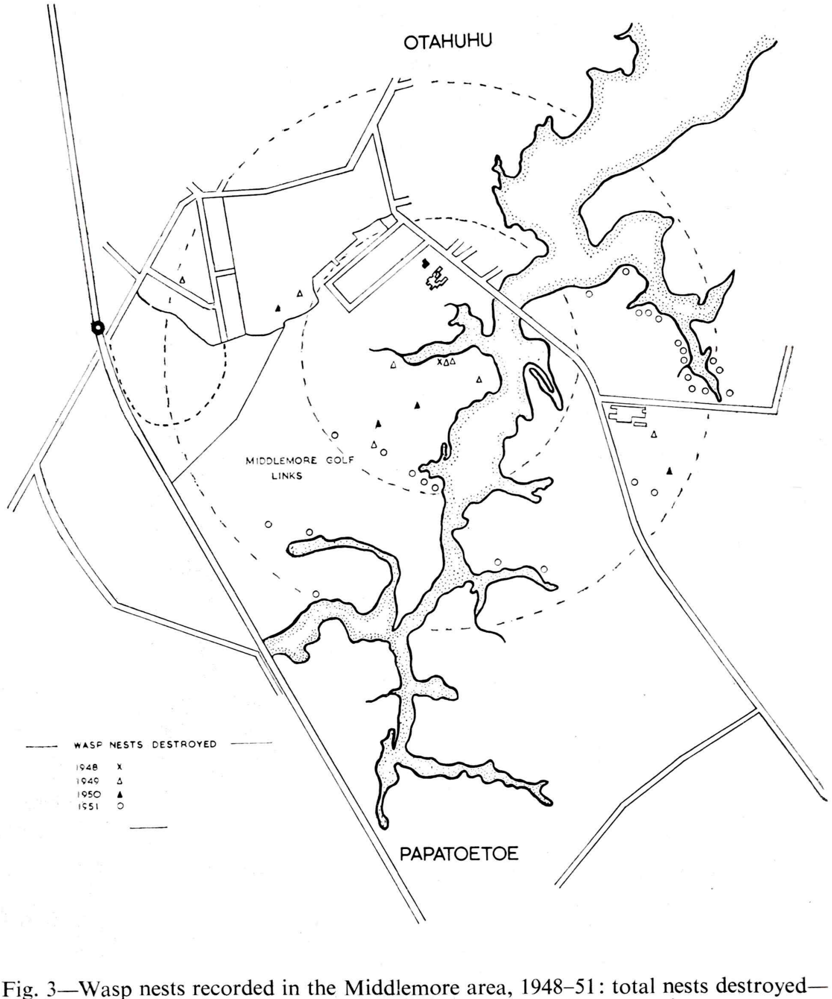


Fig. 3—Wasp nests recorded in the Middlemore area, 1948–51: total nests destroyed—1948 = 1; 1949 = 8; 1950 = 40; 1951 = 26 (approx.)

Since that time all nests discovered in the area have been reported to the Plant Diseases Division. Their approximate distribution is given in fig. 3. The map is marked with 500 and 1,000 yd radii, with the position of the wasp nest discovered in 1948 as centre.

Between 1948 and 1950 inclusive no other nests were reported within approximately five miles of this area, so it is assumed that all the nests indicated for these years were established by descendents of the original queen; but as the whole of the Middlemore area had become generally infested by 1951 the figures for that year can be considered only approximate.

The following facts apparent from a study of fig. 3 require emphasis:

1. In 1949, the second year of the infestation, the maximum distance travelled by a queen successful in establishing a nest was 880 yd.
2. In the second year of the infestation two of the nests were established within 5 yd of the parent nest and three others within 300 yd.
3. After three years the maximum distance between parent nest and progeny was approximately 1,000 yd.
4. There seems to have been an establishment period of three years, followed by a year of abundance (1951). Observations in other areas showed that this was typical of new infestations.

SOME FEATURES OF FIELD POPULATIONS OF *Vespula germanica*

PROCEDURE FOLLOWED IN TRAPPING EXPERIMENTS

To obtain information on population density and the possibilities of control by trapping, four sets of traps were set up in different localities close to Hamilton.

The trap was a modification of that developed by Newman *et al* (1941) for trapping blowflies. The side door was dispensed with and the central gauze cone made removable to facilitate collecting of trapped insects. Two standard 4-gallon tins without lids were used in the construction of each trap. Each week the traps were rebaited and counts of the number of wasps, separated into the three castes, i.e., worker, queen, and drone, were made.

The following baits were tested:

(a) *From 16 November 1949 to 16 August 1950 inclusive*

1. Bullock's liver
2. Beef
3. Fish
4. Beer diluted 1 to 10
5. Apple juice diluted 1 to 10
*6. Glucose
7. Malt
8. Dextrin
9. Sucrose
10. Honey
11. Molasses
12. Vinegar (commercial)
13. Acetic acid 10 per cent solution
14. Ethyl alcohol 20 per cent
15. Lactose 5 per cent solution
16. Spent hops

(b) *From 23 August 1950 to 28 March 1951 inclusive*

1. Molasses 10 per cent solution plus yeast
2. Beer diluted 1 to 4

(c) *From 4 April 1951 to 24 October 1951*

1. Molasses 10 per cent solution plus yeast.

---

*6–11 were used as 10 per cent solution, to which yeast was added on 7 December 1949.

Traps were located in the following areas, being spaced in line at intervals of approximately three yards:

(1) Galloway Laboratory, Hillcrest, Hamilton. A typical suburban area with a few neighbouring farmlets but no obvious nesting areas.
(2) Mr Slade's property, Matangi Road. A rural area, characterised by deep, scrub-covered gullies offering ideal nesting sites.
(3) Sandpit, Cambridge Road. Rural area as above.
(4) Mr E. Wade's property, Hillcrest, Cambridge Road. This area, bounded by the banks of the Waikato River, is characterised by deep, scrub-covered gullies. Both features offer ideal nesting sites. The traps were situated in an abandoned apple orchard, the fruit being very attractive to worker wasps.

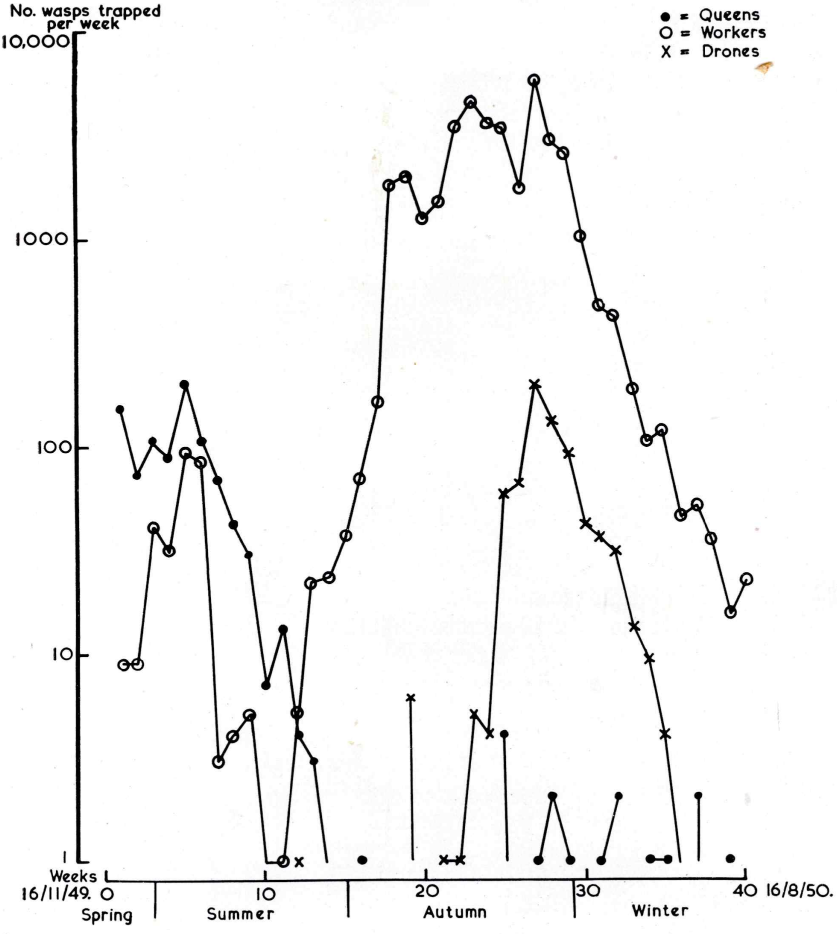


Fig. 4—Wasps trapped at Hamilton: (a) all baits and sites, 1949–50;

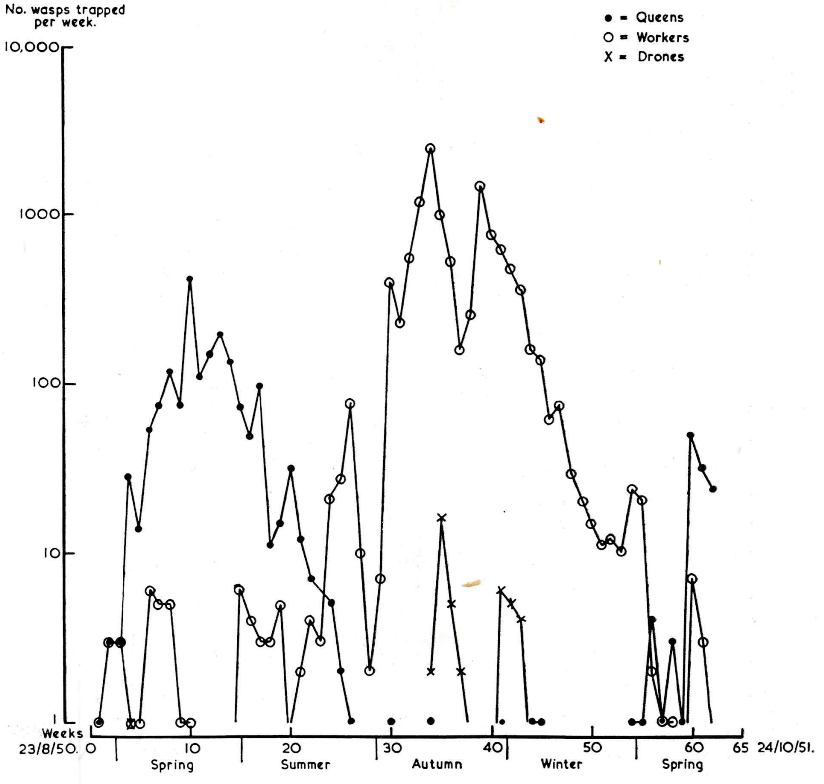
RESULTS OF TRAPPING EXPERIMENTS

The results of the first season's trapping (from 16 November 1949 to 16 September 1950) are given in tables 2–4 and the seasonal trends in the number of each wasp caste, being the total on each date from all traps and sites, are shown graphically in fig. 4A.

Results for the trapping period 23 August 1950 to 28 March 1951 (for molasses and beer) and from 4 April 1951 to 24 October 1951 (molasses only) are given in tables 5 and 6. The seasonal trends in the number of queens and worker wasps caught in the traps baited with molasses are shown graphically in fig. 4B.

Several factors influenced the number of wasps trapped:

(a) *Competition from other food sources*—At Wade's property, Hillcrest, there were eight large oak trees heavily infested with aphids. The many queen wasps attracted to the honeydew produced by these aphids resulted in a sudden increase in the wasp population in this area. That the trapped catch during the late spring at Wade's property was much greater than in other areas indicates that the materials used in the traps competed very favourably with natural foods. With inefficient attractants



(b) molasses baits, 1950–51

TABLE 2—RESULTS OF TRAPPING OF *Vespula germanica* AT GALLOWAY LABORATORY, HILLCREST, HAMILTON: FORTNIGHTLY CATCHES WITH VARIOUS BAITS

No.	Bait	Caste	23/11/49	7/12/49	21/12/49	4/1/50	18/1/50	1/2/50	15/2/50	1/3/50	15/3/50	29/3/50	12/4/50	26/4/50	10/5/50	24/5/50	7/6/50	21/6/50	5/7/50	19/7/50	2/8/50	Total No. Trapped
1	Liver	Queens	4	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	5
		Workers	..	..	1	..	..	..	..	1	2	5	11	28	9	8	2	4	2	..	..	73
		Drones	..	..	..	..	..	..	..	..	..	..	..	..	..	2	..	..	..	..	..	2
		Bees	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	1
2	Beer	Queens	46	16	14	4	3	1	..	..	..	..	..	..	..	..	1	..	..	..	..	85
		Workers	..	3	6	..	..	..	3	1	46	77	148	125	69	165	81	18	2	1	2	747
		Drones	..	..	..	..	..	..	..	..	..	..	..	..	..	6	2	1	2	..	..	12
		Bees	..	..	..	..	..	..	..	1	7	6	46	2	4	2	2	..	..	6	2	78
3	Apple juice	Queens	6	31	24	9	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	70
		Workers	1	3	9	1	..	..	..	..	7	15	9	18	24	18	11	2	..	..	..	118
		Drones	..	..	..	..	..	..	..	..	..	..	..	..	..	2	2	..	..	..	..	4
		Bees	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	1
4	Glucose	Queens	..	..	19	17	3	..	1	..	..	..	..	..	..	..	..	..	..	..	..	40
		Workers	..	..	7	..	..	..	2	..	16	36	41	90	59	63	27	2	2	1	..	346
		Drones	..	..	..	..	..	1	..	..	1	..	..	..	..	5	..	..	..	..	..	7
		Bees	..	..	..	..	..	..	..	1	..	13	36	5	8	..	2	..	..	1	..	66
5	Malt	Queens	..	..	41	28	3	1	..	..	..	..	..	..	..	..	..	..	..	..	..	73
		Workers	..	..	8	..	..	..	1	2	25	26	60	48	22	64	20	4	4	..	..	284
		Drones	..	..	..	..	..	..	..	..	..	..	..	..	..	2	1	..	1	1	..	5
		Bees	..	..	1	..	..	..	..	..	..	2	28	4	1	..	..	..	..	..	..	36

6	Dextrin	Queens	..	..	1	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2
		Workers	..	..	..	..	1	..	1	..	8	15	38	15	8	25	4	..	1	..	..	116
		Drones	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
		Bees	..	..	..	..	..	..	..	..	13	14	36	4	4	..	..	..	..	..	..	71
7	Sucrose	Queens	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	1
		Workers	..	..	..	..	..	..	2	4	20	41	28	44	84	42	30	2	3	..	..	300
		Drones	..	..	..	..	..	..	..	..	..	..	..	..	..	1	1	..	..	..	..	2
		Bees	..	..	..	..	..	..	..	..	..	5	52	23	1	..	..	..	..	..	..	81
8	Honey	Queens	..	16	32	15	2	1	1	..	..	..	..	..	..	..	..	..	..	..	..	68
		Workers	..	5	3	2	..	..	1	1	27	28	63	34	6	68	41	4	2	1	1	287
		Drones	..	..	..	..	..	..	..	..	..	..	..	..	4	3	..	..	..	..	..	7
		Bees	..	1	..	..	1	..	..	4	1	12	143	20	..	2	2	1	..	3	..	190
9	Molasses	Queens	3	24	55	11	3	..	1	..	..	..	..	..	..	2	..	..	..	..	..	99
		Workers	..	2	7	..	..	..	..	3	33	32	102	24	36	74	22	10	3	1	..	349
		Drones	..	..	..	..	..	..	..	..	..	..	..	..	..	4	..	..	..	..	..	4
		Bees	..	..	..	..	..	..	..	1	2	2	32	..	4	1	1	2	..	5	..	50
		Queens	59	87	187	81	18	3	3	..	..	..	..	..	..	..	..	..	..	..	..	..
		Workers	1	13	41	3	1	..	10	12	184	275	500	426	317	527	238	46	19	4	3	..
		Drones	..	..	..	..	..	1	..	..	1	..	1	..	..	27	9	2	1	1	..	..
		Bees	..	1	1	..	1	..	..	7	24	54	373	58	23	5	7	3	..	20	2	..
			SUMMER						AUTUMN								WINTER					

NOTE—With each of the baits beef, fish, and lactose only one wasp was caught; with beef, a worker during the period 10–24/5/50; with fish, a queen during the period 19/7–2/8/50; and with lactose, a queen during the period 23/11–7/12/49. Trapping was continued till 16/8/50, but during this period only one wasp was caught – a queen with honey.

TABLE 3—SUMMARY OF WASP TRAPPING, 1949–50: TOTAL CATCH FOR EACH BAIT AND SITE

No.	Bait	Site*	Number Trapped					
			Queens	Workers	Drones	Bees	Total Wasps (All Forms)	
1	Liver ..	(1)	5	73	2	1	80	
		(2)	3	94	4	0	101	
		(4)	0	37	1	0	38	
							—	219
2	Beef ..	(1)	0	1	0	0	1	
		(2)	1	12	0	0	13	
		(4)	0	5	0	0	5	
							—	19
3	Fish ..	(1)	1	0	0	0	1	
		(2)	1	13	0	1	14	
		(4)	0	1	0	0	1	
							—	16
4	Beer ..	(1)	85	747	12	78	844	
		(2)	74	2,598	84	14	2,756	
		(4)	40	2,887	50	2	2,977	
							—	6,577
5	Apple juice	(1)	70	118	4	1	192	
		(2)	6	262	8	0	276	
		(4)	11	983	19	0	1,013	
							—	1,481
6	Glucose ..	(1)	40	346	7	66	393	
		(2)	22	2,271	35	4	2,328	
		(4)	29	1,186	12	7	1,227	
							—	3,948
7	Malt ..	(1)	73	284	5	36	362	
		(2)	12	1,975	34	4	2,021	
		(4)	3	455	7	1	465	
							—	2,848
8	Dextrin ..	(1)	2	116	0	71	118	
		(2)	5	337	5	1	347	
		(4)	1	230	11	0	242	
							—	707
9	Sucrose ..	(1)	1	300	2	86	303	
		(2)	2	1,800	33	2	1,835	
		(4)	0	1,301	7	2	1,308	
							—	3,446
10	Honey ..	(1)	69	287	7	190	363	
		(2)	67	1,895	44	13	2,006	
		(4)	47	821	8	15	876	
							—	3,245
11	Molasses ..	(1)	99	349	4	50	452	
		(2)	19	2,118	77	6	2,214	
		(4)	7	1,091	23	0	1,121	
							—	3,787
12	Lactose ..	(1)	1	0	0	0	1	
		(2)	10	1	0	0	11	
		(4)	3	0	0	0	3	
							—	15
..	..	..	809	24,994	505	651		26,308

*Site (1), Galloway Laboratory, Hillcrest; Site (2), Slade's, Matangi Road; Site (4), Wade's, Hillcrest a decrease would normally be expected in areas where there was a strong counter attraction.

Again in the autumn of 1951 far greater catches of workers were taken at Wade's, Hillcrest. This was partly due to decaying fruit in the orchard in which traps were situated attracting many worker wasps into the vicinity. However, another factor, the proximity of traps to nests (see (d) below), undoubtedly influenced these latter counts.

(b) *Weather*—Although wasps will forage in most unfavourable weather, optimum flying conditions are probably very similar to those for the honeybee. Consequently low numbers in trapping records are ofte

TABLE 4—SUMMARY OF WASP TRAPPING, 1949–50: TOTAL WEEKLY CATCHES, ALL TRAPS AT THREE SITES

Date	Queens	Workers	Drones	Bees	Total Wasps
16/11/49	86	8	0	0	94
23/11/49	67	9	0	0	76
30/11/49	126	40	0	1	166
7/12/49	78	30	0	2	108
14/12/49	221	90	0	0	311
21/12/49	99	80	0	0	179
28/12/49	66	3	0	0	69
4/1/50	41	4	0	0	45
11/1/50	28	4	0	0	32
18/1/50	12	0	0	1	12
25/1/50	2	0	0	0	2
1/2/50	13	4	1	0	18
8/2/50	3	17	0	0	20
15/2/50	1	16	0	0	17
22/2/50	0	26	0	13	26
1/3/50	0	38	0	3	38
8/3/50	1	133	0	3	134
15/3/50	0	1,066	1	34	1,067
22/3/50	0	1,002	2	36	1,004
29/3/50	0	710	0	38	710
5/4/50	0	924	1	314	925
12/4/50	0	2,101	0	67	2,101
19/4/50	0	3,188	3	60	3,191
26/4/50	0	1,924	0	4	1,924
3/5/50	1	2,335	27	16	2,363
10/5/50	0	1,369	15	8	1,384
17/5/50	1	4,138	164	2	4,303
24/5/50	2	2,133	114	3	2,249
31/5/50	1	1,963	69	4	2,033
7/6/50	0	711	36	3	747
14/6/50	1	364	24	1	389
21/6/50	1	220	22	0	243
28/6/50	0	125	7	0	132
5/7/50	1	60	6	0	67
12/7/50	0	73	3	21	76
19/7/50	0	43	0	0	43
26/7/50	2	38	0	2	40
2/8/50	0	31	0	0	31
9/8/50	1	14	0	0	15
16/8/50	0	20	0	0	20
	855	25,054	495	636	26,404

an indication of continuous inclement weather rather than of true population variations.

(c) *Changes in diet*—Actual changes in the diet of queen wasps are not apparent. However, marked changes occur in the diet of worker wasps during the active season. Early in the season worker wasps are engaged in collecting insects and other animal matter, but in mid March there is a sudden change to a predominantly sweet diet (see pp. 14 15). This accounts for the low figures of February and early March, the sudden peaks of 15 March 1950 and 14 March 1951 being an indication of this changeover in diet.

(d) *Proximity of nests to traps*—The nearness of traps to nests is obviously an important factor influencing the number of insects trapped. This partly accounts for the larger number of workers captured at situations (2), (3), and (4) as compared with the low counts at Galloway Laboratory, where the number of nests was very limited. The position of individual traps in each set also influenced counts. Autumn counts were usually considerably higher in a trap which was closer to a large, heavily infested gully at Hillcrest.

Dilute beer was the most attractive substance tested and remained so for the longest period. Glucose, molasses, sucrose, honey, and malt were only slightly less attractive than beer, and their attractiveness was improved by the addition of yeast. Apple juice, dextrin, and lactose were much less attractive, while vinegar, acetic acid, ethyl alcohol, and spent hops appeared to have no attraction for any caste of wasp.

Although exposed meat, particularly if freshly killed, is attractive to wasps it is apparent from tables 2 and 3 that meal baits are of little value

TABLE 5—SUMMARY OF WASP TRAPPING, 1950–51: TOTAL CATCH FOR EACH BAIT AND SITE

Bait	Site*	Number Trapped				
		Queens	Workers	Drones	Total (All Forms)	
1. Molasses 23/8/50–28/3/51	(1)	448	300	1	749	
	(2)	249	434	0	683	
	(3)	451	205	0	656	
	(4)	547	432	0	979	
					—	3,067
2. Beer 23/8/50–28/3/51	(1)	261	94	3	358	
	(2)	210	121	0	331	
	(3)	366	86	0	452	
	(4)	502	297	1	800	
					—	1,941
3. Molasses 4/4/51–24/10/51	(1)	44	759	1	804	
	(2)	26	2,904	21	2,951	
	(3)	40	1,164	4	1,208	
	(4)	26	5,238	9	5,273	
					——	10,236

*(1) Galloway Laboratory, Hillcrest; (2) Slade's, Matangi Road; (3) Sandpit, Cambridge Road; (4) Wade's, Hillcrest.

in trapping them. A further disadvantage is that the meat soon becomes fouled by flies and requires frequent rebaiting. This also applies to fish.

Except at the Galloway Laboratory, the number of honeybees trapped was insignificant. While natural sources of nectar were plentiful in the spring and early summer few bees were captured, and not until the time when the older bees were scavenging did the count increase to any great extent. The majority of bees trapped were attracted to the honey bait.

Counts of drone wasps revealed a peak occurring in mid May in 1950, that is, at a time when nest activity begins to decline following mating of young queens, and when, in the absence of food normally supplied by the workers, the drones forage for themselves. Even so, few drones were captured because they reside within the nest for the greater part of their life.

No true peak was obtained for the flight of queen wasps in 1949 as the spring was well advanced before the traps were set out. However, in the spring of 1950 a definite peak occurred on 25 October in areas (1), (2), and (3), and on 15 November at (4).

Both trap records and extensive field observations indicate that mated queens do not forage before hibernating. The capture of single queens on 8 March 1950 (table 4), 14 March 1951 (table 6), and 11 April 1951 (table 6) is possibly explained by the fact that they were induced by the design of the traps to enter through the slit-like openings while searching for hibernation sites. Likewise, the capture of queen wasps throughout the winter was probably the result of their leaving hibernation on warm days and either attempting to feed or being captured while searching for new hibernation sites.

Worker wasps were most abundant in late April and early May (figs. 4A and 4B). During winter, spring and early summer of each year worker wasps from over-wintering nests were captured in varying numbers (see figs. 4A and 4B).

TABLE 6—SUMMARY OF WASP TRAPPING, 1950–51: TOTAL WEEKLY CATCHES, ALL TRAPS AT THREE SITES

Date	Queens	Workers	Drones	Total
23/8/50	3	10	1	14
30/8/50	5	15	2	22
6/9/50	7	10	0	17
13/9/50	56	5	1	62
20/9/50	61	10	0	71
27/9/50	146	13	0	159
4/10/50	190	12	0	202
11/10/50	256	17	1	274
18/10/50	174	9	0	183
25/10/50	660	3	0	663
1/11/50	180	0	0	180
8/11/50	264	0	0	264
15/11/50	376	0	0	376
22/11/50	172	0	0	172
29/11/50	134	6	0	140

TABLE 6—SUMMARY OF WASP TRAPPING, 1950–51: TOTAL WEEKLY CATCHES, ALL TRAPS AT THREE SITES—*continued*

Date	Queens	Workers	Drones	Total
6/12/50	101	8	0	109
13/12/50	129	5	0	134
20/12/50	23	0	0	23
27/12/50	18	6	0	24
3/1/51	47	0	0	47
10/1/51	20	2	0	22
17/1/51	9	4	0	13
24/1/51	0	3	0	3
31/1/51	7	22	0	29
7/2/51	2	29	0	31
14/2/51	2	113	0	115
21/2/51	1	65	0	66
28/2/51	0	28	0	28
7/3/51	0	85	0	85
14/3/51	1	495	0	496
21/3/51	0	273	0	273
28/3/51	0	721	0	721
4/4/51*	0	1,197	0	1,197
11/4/51	1	2,452	2	2,455
18/4/51	0	1,002	16	1,018
25/4/51	0	533	5	538
2/5/51	0	161	2	163
9/5/51	0	263	0	263
16/5/51	0	1,498	0	1,498
23/5/51	0	775	0	775
30/5/51	1	743	1	745
6/6/51	0	484	5	489
13/6/51	0	361	4	365
20/6/51	1	162	0	163
27/6/51	1	138	0	139
4/7/51	0	63	0	63
11/7/51	0	74	0	74
18/7/51	0	32	0	32
25/7/51	0	20	0	20
1/8/51	0	15	0	15
8/8/51	0	11	0	11
15/8/51	0	12	0	12
22/8/51	0	10	0	10
29/8/51	5	24	0	29
5/9/51	1	20	0	21
12/9/51	4	2	0	6
19/9/51	3	1	0	4
26/9/51	3	1	0	4
3/10/51	16	1	0	17
10/10/51	34	7	0	41
17/10/51	32	3	0	35
24/10/51	24	0	0	24
	3,170	12,034	40	15,244

*Molasses baits only after 4/4/51.

THE LIFE HISTORY OF *Vespula germanica* IN NEW ZEALAND

FOOD AND WATER

Until late December queens can often be observed feeding on a variety of plants. Honeydew is usually the principal source of food in the Waikato, but nectar is also collected. However, because the mouth parts of *V. germanica* are comparatvely short, only the nectar of flowers with short corollas is accessible. The periods of availability of the principal plant-food sources of queen wasps in New Zealand are given in table 7. Many other plant foods are undoubtedly available to queen wasps and more extensive observations would probably show that some of the sources indicated are available for longer periods than indicated, but it is clear that there is a regular succession of food plants available from early spring until midsummer, i.e., during the period when queens are establishing nests. In New Zealand other reported sources of food include the sap from leaves on cacti and honeydew produced: by aphids on cypress; by the scale *Eriococcus coriaceous* Mask. on eucalypts; by insects infesting barberry hedges; by the aphid *Cavariella aegopodii* Scop. on willow; by aphids on hickory shrubs; by insects infesting poplars; by *Scolypopa australis* Walk. on *Coriaria arborea* Lind.; and by insects infesting ripe fruit of blackberries. However, there can be no doubt that the common oak, *Quercus robur* L. and certain species of *Cotoneaster* yield queen wasps the greatest proportion of their food during the spring flight. In early spring the young oak leaves become heavily infested with the aphids *Myzocallis annulatus* Hartig or *M. castanicola* Baker, the latter being more common. Sometimes both occur. As the aphid population increases, large quantities of honeydew are excreted. In fact, under heavily infested trees the honeydew may fall as a fine mist. However, the rate of honeydew production declines as the foliage matures. Heavy rain tends to remove the honeydew, heavy dews render the honeydew more viscous, and on hot days the honeydew dries. These changes alter the attractiveness of the trees to wasps. After heavy rain, or hot dry days, less insects visit the trees than after a heavy dew. The nectar of certain species of *Cotoneaster* is the other principal source of food. At present only *C. simonsii* Baker and *C. franchetti* Bois. are known to attract wasps in New Zealand, but as the genus includes over 40 species this list may later be extended.

Wasp larvae are fed by the foraging workers with insects and other animal matter such as meat and fish. There is, however, no doubt that the bulk of the diet comprises insects and, to a lesser extent, spiders.

Worker wasps, particularly in the early part of the season, are commonly seen on freshly killed meat. This is most attractive to them and hunters

TABLE 7—THE PRINCIPAL PLANT FOOD SOURCES OF QUEENS OF *V. germanica* IN NEW ZEALAND

Plant	Food	Period When Food Eaten						Remarks
		Aug	Sep	Oct	Nov	Dec	Jan	
Citrus sp.	Honeydew excreted by scale *Saissetia oleae* Bern.		—	—	—			
Rhododendron sp.	Nectar and sap exudate of buds		—	—	—			
Banksia ericifolia L. (Bottle-brush)	Nectar		—					Overwintering workers only.
Climbing rose	Honeydew excreted by aphid *Myzaphis rosarum* Van der Goot		—	—				
Araucaria excelsa R.Br. (Norfolk pine)	Honeydew excreted by mealy-bug *Pseudococcus aurilanatus* Mask.			—				
Araucaria bidwillii Hook. ..	,,			—				
Quercus cerrus L. (Turkey oak)	Honeydew excreted by aphids *Myzocallis castanicola* Baker, *Myzocallis annulatus* Htg. ..			—				
Prunus serrulata Lindl. (Cherry)	Nectar			—				
Camellia japonica L. ..	,, ...			—				
Crataegus oxyacantha L. (Hawthorn)	Honeydew excreted by scale *Saissetia oleae* Bern. ..				—	—	—	
Eleagnus pungens Thunb ..	Honeydew excreted by aphis *Capitophorus eleagni* Del G.			—	—			
Platanus orientalis L. (Oriental plane)	Honeydew excreted by scale *Saissetia oleae* Bern. ..			—				

TABLE 7—THE PRINCIPAL PLANT FOOD SOURCES OF QUEENS OF *V. germanica* IN NEW ZEALAND—*continued*

Plant	Food	Period When Food Eaten						Remarks
		Aug	Sep	Oct	Nov	Dec	Jan	
Acer pseudoplatanus (Sycamore maple)	Cercopid secretion			—				
Crataegus mexicana Sess. and Moc.	Nectar				—			
Viburnum sp.	Honeydew excreted by scale *Saissetia oleae* Bern. . .				—			
Ligustrum lucidum Ait. (Privet)	Cercopid secretion				—			
Telopea speciossisima R.Br. (Waratah)	Nectar			—	—	—		
Plum	Honeydew			—	—			
Juniperus communis L. (Juniper)	Honeydew excreted by aphid *Neochmosis juniperi* Geer. . .		—	—	—			
Pittosporum crassifolium A. Cunn.	Honeydew excreted by chermid *Powellia vitreoradiata* Mask.					—		
Cotoneaster simonsii Baker . .	Nectar				—	—		A few overwintering workers also attracted.
Cotoneaster franchetti Bois. . .	Nectar				—	—	—	
Quercus robur (Oak) . .	Honeydew excreted by *Myzocallis castanicola* Baker and *Myzocallis annulatus* Htg.			—	—	—		A few overwintering workers also attracted.

in remote areas are often troubled while attempting to skin deer, goats, etc. Fish, both cooked and raw, is also favoured and anglers in the central North Island have complained on many occasions of wasps being attracted in large numbers to recently caught trout.

Live insects are attacked, by the worker wasps, both in flight and while at rest. Many different insects are preyed upon, although the majority are Diptera. Size is no deterrent and it is not uncommon in New Zealand to see large dragonfles and crane flies attacked and killed by the workers.

Earlier investigators believed that the sting of the wasp was used to paralyse the prey. This has not been observed in New Zealand. If the captured prey is large it is dismembered before the worker returns to the nest. Some parts, presumably low in nutritive value or too highly chitinised, such as legs and wings, are cut away by the mandibles as also is usually the head and sometimes even the thorax. While this is being accomplished the worker clings to some support by the two rear pairs of legs, the front pair of legs holding the prey. When dismembering is complete the thorax and abdomen (or abdomen alone) are crushed and the body juices are imbibed by the worker. After a short period the wasp returns to the nest where the prey is fed to the larvae. Sometimes the prey, for example a large dragonfly, is too large to be carried back to the nest in one piece. Then it is cut into several portions, sometimes as many as six or eight, which are carried to the nest one at a time. If the pieces are removed or shifted during the wasp's absence, the wasp returns directly to the site where the pieces were initially and then searches the immediate surrounds for some minutes until either the portions are found or the search abandoned.

Because the prey is not completely masticated it is possible partly to recognise the fragments and determine what insects are preyed upon. Larval food taken from foraging workers netted when returning to their nests consisted of: one fragment of a blowfly, *Calliphora* species; two fragments of unidentified diptera; one caterpillar, *Cirphus unipuncta*; and two fragments of unidentified spiders. After fumigation of a nest by calcium cyanide the following fragments were removed from mandibles of the dead workers:

Odonata :	4 fragments of *Austrolestes colensonis* Wh.
Diptera:	8 fragments of Muscidae
	3 fragments of *Calliphora* sp.
	1 fragment of Stratiomyid
	1 larva and 3 fragments of Tipulids
	2 fragments unidentified
Lepidoptera:	1 moth, 1 *Cirphus unipuncta* Haw. caterpillar
Spiders:	2
Unidentified:	4

From the time when the first workers appear in February until mid March and early April wasps choose an animal protein regimen and rarely feed on sweets. When the drones appear workers develop an insatiable desire for sweets, and from then until death of the colony in late May workers seek out and feed upon sweet materials. Table 8 contains

TABLE 8—THE PRINCIPAL PLANT FOOD SOURCES OF WORKERS OF *V. germanica* IN NEW ZEALAND

Date	Plant	Food	Remarks
15/3/49	*Cupressus macrocarpa* Hartw.	Honeydew excreted by aphid *Neochmosis juniperi* Geer.	
15/3/49	*Araucaria bidwillii* Hook.	Honeydew excreted by mealybug *Pseudococcus aurilanatus* Mask.	
24/4/49	*Hedera helix* L. (Ivy)	Nectar secreted from base of ovary	Still very attractive, even after petal fall.
3/5/49	*Quercus robur* L. (Oak)	Honeydew excreted by aphid *Myzocallis castanicola* Baker	Small quantity produced after short period of new growth.
3/5/49	*Araucaria excelsa* R. Br. (Norfolk pine)	Honeydew excreted by *Pseudococcus aurilanatus* Mask.	
17/8/49	*Rhododendron* sp.	Nectar and sap exudate of buds.	
7/2/50	*Eucalyptus* sp.	Honeydew excreted by scale *Eriococcus coriaceous* Mask.	
27/2/50	..	Secretion surrounding Fulgaroid egg masses.	
7/3/50	*Abutilon* sp.	Honeydew excreted by scale *Saissetia oleae* Bern.	
10/3/50	*Hebe* sp.	Honeydew excreted by *Scolypopa australis* Walk.	
20/3/50	*Sonchus oleraceus* L. (Sowthistle)	Honeydew produced by aphid *Macrosiphum euphorbiae* Thomas.	
6/4/50	*Quercus robur* L. (Oak)	Sap bleeding from cut limbs.	
11/5/50	*Leptospermum ericoides* A. Rich. (Manuka)	Sap bleeding from wounds produced by wood-boring larvae.	
21/5/50	*Citrus* sp.	Honeydew excreted by aphid *Aphis citricidus* Kirk.	

the author's observations of the plant-food sources of worker wasps in New Zealand.

In addition, officers of the Department of Agriculture have observed worker wasps feeding on: sap bleeding from wounds of *Pittosporum crassifolium* A. Cunn.; honeydew produced by scales on *Leptospermum ericoides* A. Rich.; and nectar of Michaelmas daisies.

Both workers and drones feed on damaged fruits, including grapes, apples, figs, pears, quinces, strawberries, plums, peaches, and nectarines; also on honey, jam, sauces, beer, wine, soft drinks, whey, etc. It is during their constant search for such materials that they enter houses and become a nuisance.

In addition to these foods both drones and workers imbibe the salivary secretions of the larvae. This is produced in small globules when the larvae are stimulated on the back of the head. In caged nests drones were often seen clustered on the under side of the brood combs with their heads dipped in the cells containing mature larvae, presumably imbibing the larval secretion.

Collection of water—Large quantities of water are imbibed by foraging workers. The amount of water collected appears to be far in excess of the needs of the individual forages and the fact that the latter, after imbibing, return directly to the nest, indicates that most of this water is probably used within the nest rather than by the workers alone.

Some authors claim that this water is used to cool the nest, but *V. germanica* does not appear to utilise this method of temperature regulation; indeed, the task in a large nest would be colossal. Rather it would appear that water is used partly to moisten soil during excavation of the nest cavity, and partly to knead fibre for the construction of combs and nest envelopes. It is not known whether the larvae and the teneral individuals are given water.

That wasps return directly to the nest after imbibing water has been used extensively in New Zealand as a means of locating nests, as in the experience of the author, these are rarely more than 400 to 500 yd distant from the water supply.

HIBERNATION

In the autumn, following mating, queen wasps immediately seek out suitable hibernating sites. Shelter from direct sunlight and a degree of protection from the weather appear to be the main prerequisites for a hibernaculum. Queens are found in both damp and dry locations, but cannot tolerate excessive moisture.

The pose adopted by queen wasps during hibernation is very characteristic and has been excellently described by Duncan (1939).

In New Zealand queen wasps have been found in hibernation as late as 10 November and as early as 16 March.

Queens have been found in the following hibernacula: in the folds of damp sacks; in old clothing; in blankets; between the folds of curtains; in wrapping around bacon; in railway tarpaulins; between paper fertiliser bags; beneath the bark of dying trees and shrubs (particularly *Cupressus macrocarpa* Hartw.); in larval tunnels in old logs; under tiles on houses; under corrugated roofing; in coal in rail trucks; under beehive lids; in stacked timber; and in overwintering wasp nests either between disused combs or between the outer nest envelope and the walls of the nest cavity.

On warm winter days queen wasps may leave their hibernating quarters and after a short period of free flight find new hibernacula. Queens have been seen leaving and entering spaces between roof purlins and corrugated roofing. At the Galloway Laboratory wasp traps were placed on a wooden verandah leaving a space in which queens could hibernate. Here, on many occasions throughout the winters of 1950 and 1951 when the traps were lifted and rebaited each week, varying numbers of hibernating queens were found.

Some queen wasps die in hibernation. Dead specimens are often found in hibernacula, and in moist places fungi may be responsible for the death of queens, while many are killed by mice.

Sandeman (1936) found 68 queen wasps under the bark of a fallen ash tree in England, and considered such a large number to be an unusual occurrence. In New Zealand queen wasps were often found hibernating together in large numbers and counts of up to 400 were quite common. During a publicity campaign lasting approximately three months in the spring of 1948, 118,000 hibernating queens were collected (over 7,000 by one schoolboy). Occasional workers were found hibernating under the bark of trees in the winter of 1948, but drones were not observed to hibernate away from the nest.

In New Zealand there is no true hibernation of either drones or workers in the nest. Sometimes, however, low temperatures induce a brief semi-dormant phase in overwintering nests.

THE SPRING FLIGHT OF THE MATED QUEENS

In late August and early September, following the first few days of warm spring weather, queen wasps leave hibernation and attempt to establish nests. Until late December queens can often be observed feeding at a variety of plants. Nectar is collected from a few flowers but, in the Waikato, honeydew from aphids and scales is usually the principal source of food.

Normally by midsummer the successful queens have established their nests, the remainder having died while attempting to found a colony.

ESTABLISHMENT OF THE COLONY

Selection of the Nesting Site

Some time during the spring flight a queen chooses a site in which to establish her nest. Duncan (1939) considers that wasps do not exercise the extraordinary foresight in the selection of nesting sites that has sometimes been attributed to them, and this is the case in New Zealand. Indeed, many of the nesting sites chosen are so inadequate that enlargement is impossible and many nests are begun in situations where protection is all but non-existent. Most of these nests are abandoned after several weeks. "Queen" nests have been found hanging exposed from ceilings, verandahs, and under branches of trees, but with few exceptions these too had been deserted by the queen.

Overseas, *V. germanica* is typically a ground-nesting species. In New Zealand, however, aerial nests of this species are very common, particularly in bush and well populated areas. In both areas it is probable that suitable ground-nesting sites are rather scarce.

Some of these aerial sites include: hanging from a rafter in a tool shed; under roofs of buildings; the space between weatherboards and lining of houses; disused beehives (fig. 5); a packing case containing aeroplane parts (fig. 6); a roll of paper lying under a house; beneath branches of

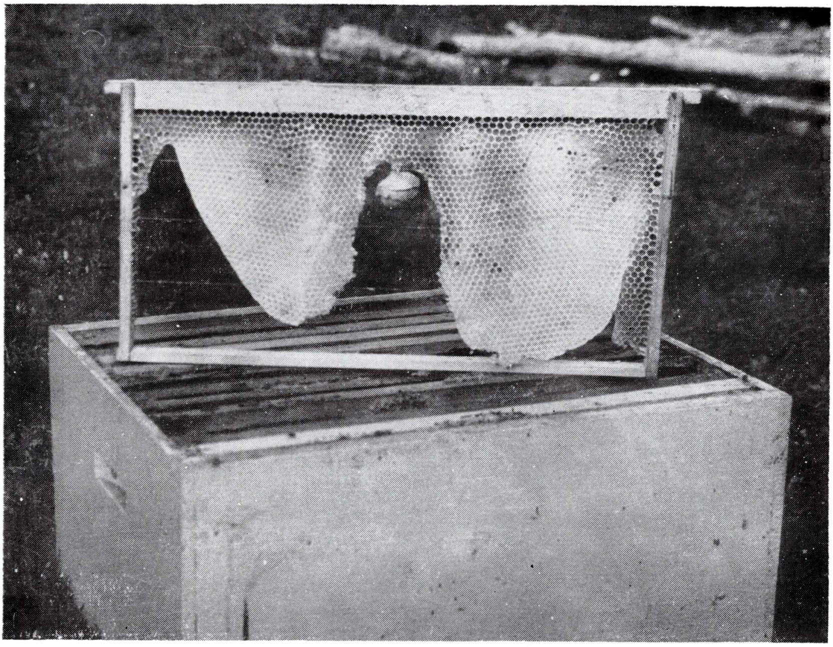


Photo: C. R. Thomas

Fig, 5—Nest of *V. germanica* on frame in disused beehive super

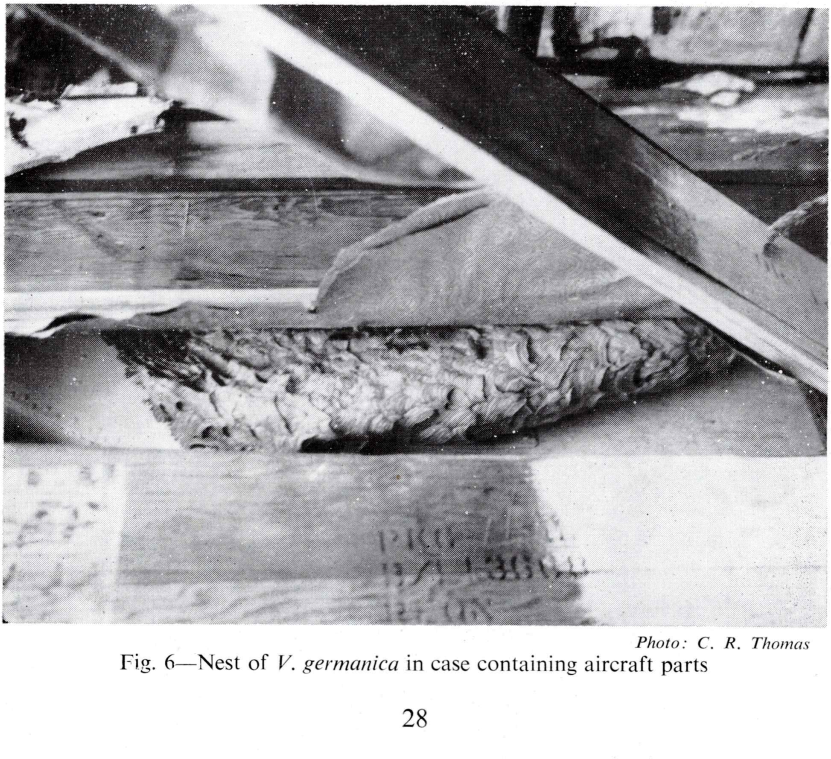


Photo: C. R. Thomas

Fig. 6—Nest of *V. germanica* in case containing aircraft parts

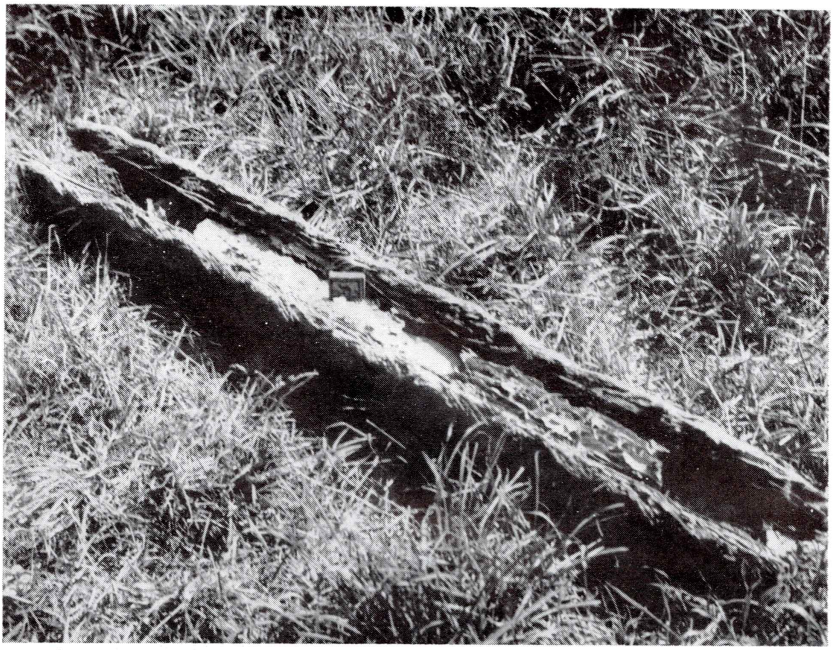


Photo: C. R. Thomas

Fig. 7—Nest of *V. germanica* in hollow tree fern log

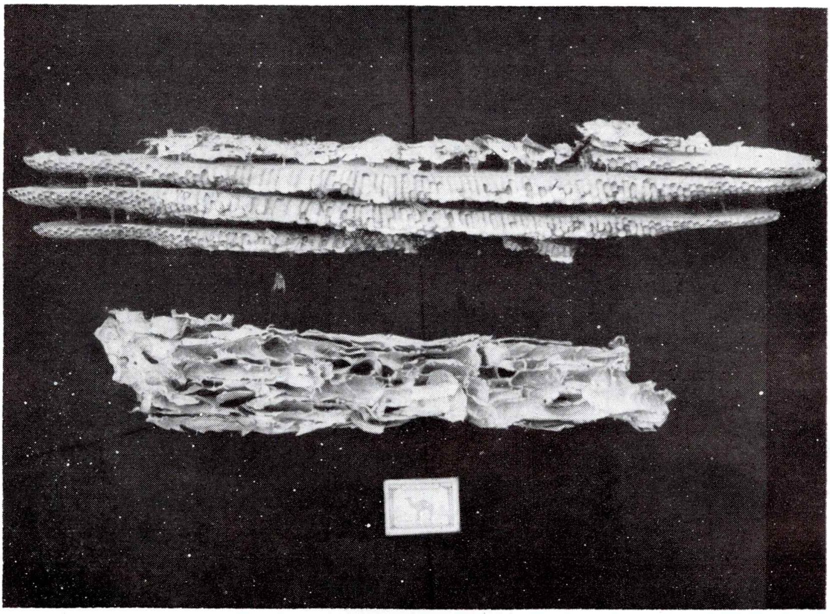


Photo: C. R. Thomas

Fig. 8—Nest removed from tree-fern log (fig. 7): note plug of paper shown in lower half of figure

trees overhung by creepers and grasses, etc.; hollow trees and rotting logs (figs. 7 and 8).

Nevertheless the majority of nests are subterranean, being established in disused cricket burrows, rodent holes, or in fissures in those heavy clay soils which crack readily in the early summer (fig. 9). Ploughed land has in several instances provided many sites for queens. A ploughed field at Kaipaki, Waikato, yielded 16 nests from 5 acres in the autumn of 1948. In the same year, during construction of an embankment for a railway line at Ngaruawahia, spoil was deposited over a 30-acre paddock. The hummocks were ideal for the establishment of many nests and in 1948, 107 nests were destroyed there. In 1949, in the same area, only 5 nests were discovered.

Nests have been found in most soil types, but heavy clays restrict the rate of enlargement, the larger nests generally being found in loose, sandy soils. Indeed, the rate at which the nest cavity can be excavated appears to be the main factor limiting the size of underground nests. The comparatively huge size of aerial nests and nests begun in unrestricted situations would lend support to this view. Other nests have been found under rubbish heaps, in haystacks, in sawdust, and in rock walls. Although nests are usually situated close to the ground surface, entrance galleries of 2 or 3 feet in length are common. These galleries may penetrate the ground in any direction but usually pass downward, the nest lying below the level of the entrance.

One nest worthy of note was found in April 1948. A stone and motar retaining wall stood at the bottom of a clay bank. The entrance to the nest was through the wall by way of a rock fissure so small that only a single wasp could pass through at a time. When the nest was dug out a gallery nearly three feet long was found leading from the entrance to the nest, which was compressed into a concertina shape. The workers had not removed much of the hard clay, but had built small sections of comb into the irregularities of the adjacent rocks until further enlargement of the nest was almost impossible. The excavated clay had been used to plaster the walls of the gallery leading to the nest.

Nests have been found established in swamps, only a few inches above water level. Apparently workers cannot excavate excessively moist soil and, unable to extend the nest downward, the combs are added to in a horizontal plane, queen cells being attached in lobes, resulting in a characteristic fan-shaped nest (fig. 10). Such nests, common in the Rukuhia Swamp, near Hamilton, became flooded when heavy rain raised the water level.

Excavation of the Nest Cavity

Following the selection of the nesting site, the queen excavates a sufficient space in which to start the nest. Often there is already sufficient space, as in rodent burrows, large earth fissures, etc.

From an examination of the nest cavity walls it is apparent that the soil is kept moist by the queen (and worker wasps) during excavation. Presumably much of the large quantity of water carried to the nest is

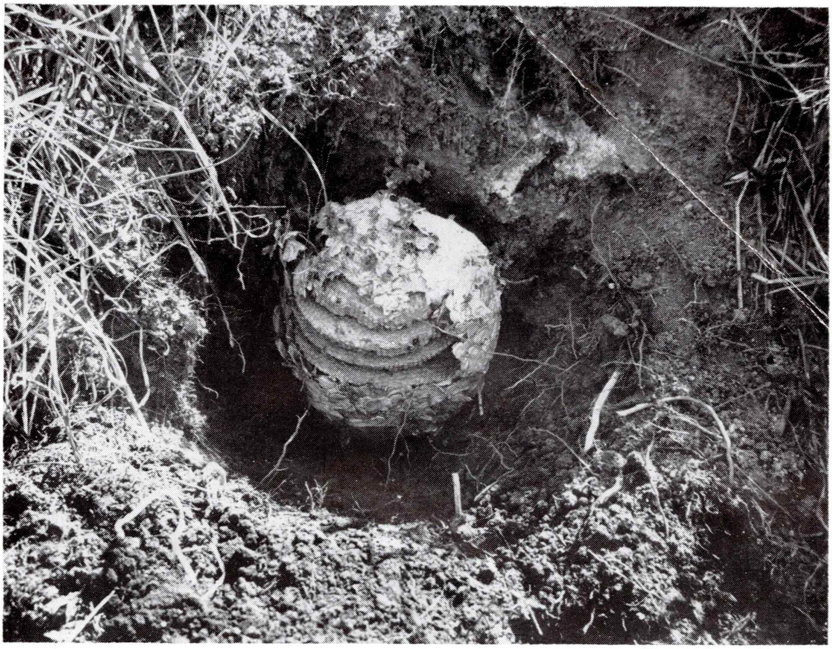


Photo: C. R. Thomas

Fig. 9—Typical nest of *V. germanica in situ:* a portion of the nest envelope has been removed

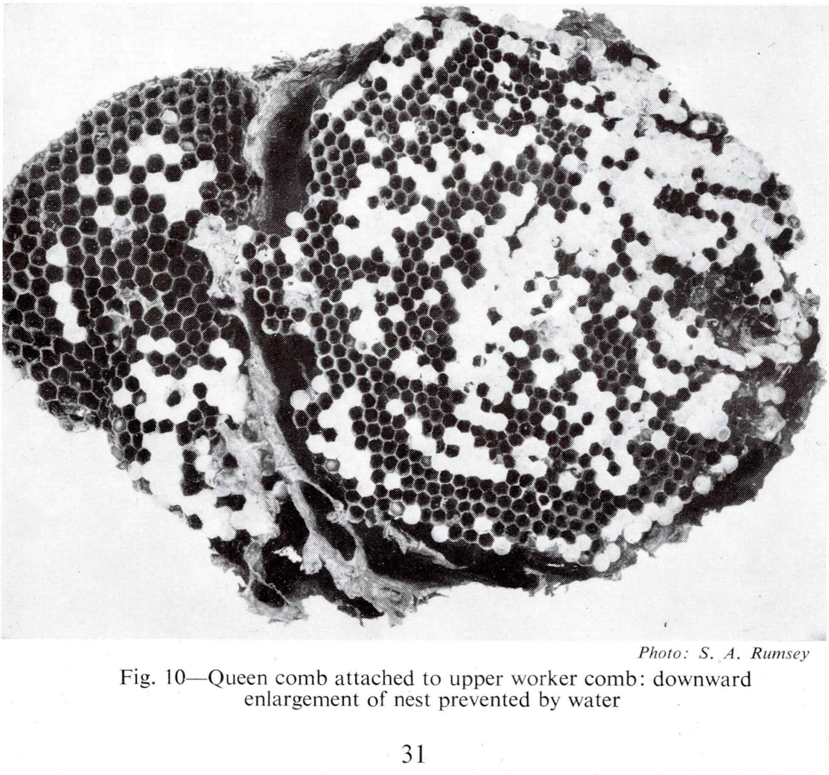


Photo: S. A. Rumsey

Fig. 10—Queen comb attached to upper worker comb: downward enlargement of nest prevented by water

regurgitated and kneaded with the sub-soil into small pellets of $\frac{1}{8}$–$\frac{3}{16}$ in. diameter. When the pellet is of sufficient size it is grasped in the mandibles and, with the assistance of the fore legs, is carried to the nest entrance. There the queen (or workers) attempts to fly away with the pellet, sometimes requiring three or four attempts to become airborne. With such a comparatively heavy load flight is only sluggish, but although wasps have been followed for over 100 yards they have never been seen to drop their load.

Often, after several unsuccessful attempts to ascend with heavy pellets, they are simply rolled from the nest entrance where they tend to accumulate and become a very characteristic feature of subterranean nests, especially those constructed in clay soils (fig. 11). Often these pellets are not brought to the surface but are used to line the gallery leading to the nest. Cracks in the ground, or crevices in rocks, are tightly packed, perhaps to afford insulation of the nest, which appears to be of prime consideration at all times. Large pebbles and rocks may be encountered during excavation. After the soil is removed from around these they fall to the bottom of the nest cavity and, particularly in alluvial ground, may occupy the greater part of the nest floor. Small roots are gradually chewed away and the fibre utilised in nest construction, while larger roots are built into the nest.

With the possible exception of newly emerged adults, excavation appears to be a function of all foraging workers (and initially the queen) in the

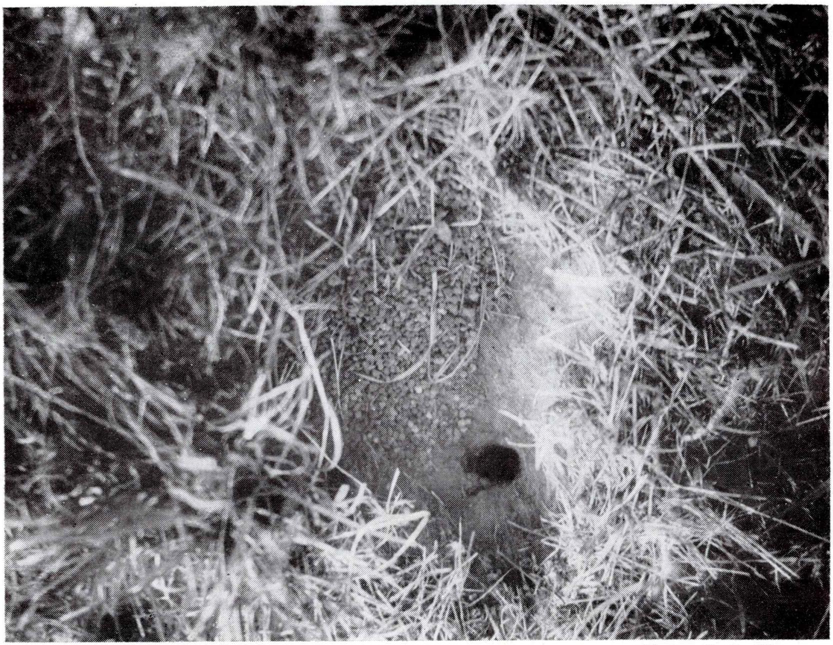


Photo: C. R. Thomas

Fig. 11—Entrance to a nest of *V. germanica:* note excavated pellets outside the nest

nest, for workers are rarely seen leaving the nest without a load of excavated material.

Selection of Fibre for Nest Construction

Wasps are most selective in their choice of fibre with which to construct the nest. Fibre that is well weathered, but not decayed, is gathered from various sources. Wood fibre from telegraph poles and paling fences is most preferred, although the bark of trees is often stripped off. Wasps have been observed gathering fibre from dahlias, lilac, macrocarpa, and, indeed, any timber that is well weathered and has a straight grain from which the fibres can readily be cut away. In heavily infested areas characteristic patterns are left on timber from which fibre is gathered.

Although the collection of fibre is a function of many of the workers in a nest, they appear to work independently, marked wasps repeatedly returning alone to a particular place; this ability of wasps from a single nest to work independently rather than as a group is a marked characteristic of wasp behaviour.

The collection of each load of fibre for the nest is a lengthy procedure involving considerable effort. After alighting on the weathered material the wasp grasps the surface firmly with the hind and middle legs. Then, with a biting motion of the mandibles, the fibre is moistened and scraped together. As the worker moves gradually backward the fore legs form the fibre into a neat ball. When this reaches a diameter of approximately $\frac{1}{8}$ in. the wasp ascends and returns directly to the nest. There the ball of fibre is unrolled and kneaded onto a free edge of the nest envelope, and although only loosely attached at first, the action of the mandibles and the secretion of saliva soon secure it to form a paper-like substance. In aerial nests (and probably subterranean nests also) all the field-collected fibre is used in the construction of the outer envelope surrounding the brood combs.

The Queen Nest

With her first loads of fibre the queen moulds an attachment (suspensorium) to what will be the main support of the nest, usually a root or some other irregularity. The fibre is well masticated and plastered around the support* until a strap-like structure with a widened upper portion is produced. At the base of this the first brood cells are constructed.

Active construction of a queen nest has not been observed. The sequence of events probably follows that given by Duncan (1939) for aerial building species of *Vespula* (figs. 12 and 13).

After the base for a few cells has been constructed, the queen commences egg-laying. A single egg† is laid in each cell. The eggs are firmly attached by the apex, usually to the wall nearest the centre of the comb, an adhesive substance secreted by the queen fixing the eggs so that they point downward towards the cell mouth. There, according to Imms (1938), the larvae

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*Some writers consider the point of attachment of the suspensorium is first coated with an adhesive, shellac-like secretion, but this cannot be seen in nests of *V. germanica*.

†During the late autumn nests are sometimes found with cells containing as many as 12 eggs. These eggs are probably laid by the workers.

hatch within a few days. In New Zealand the period is about three to four days.

As the developing larvae, now fed by the queen, increase in size, the cell walls are gradually built down with paper torn from the inner surface of the envelope. After three moults the larva spins a silken cocoon. At the closed end of the cell the cocoon is absent, but is thicker towards the cell

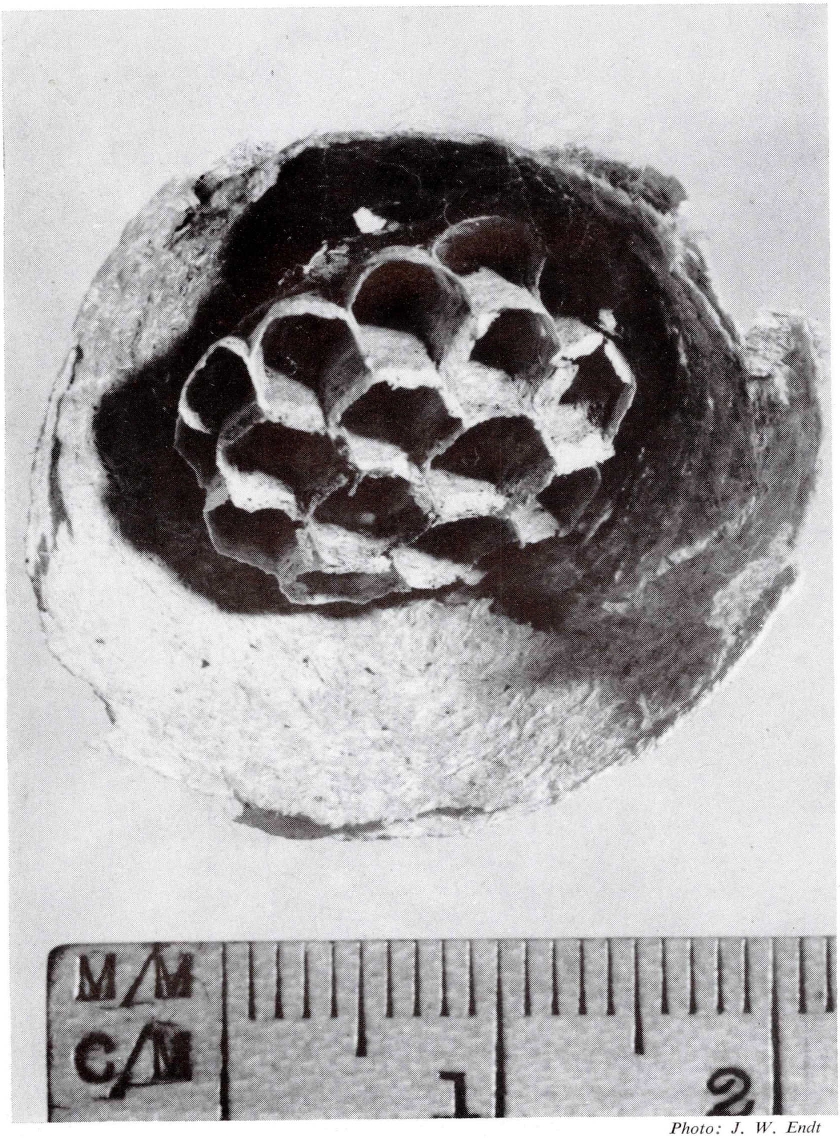

Photo: *J. W. Endt*

Fig. 12—Queen nest of *V. germanica:* outer envelope partly removed to show first cells of nest

mouth, which is closed eventually by a tough membrane; the larva then passes into the pupal stage.

Immediately after the cocoon is completed the contents of the gut are evacuated. This faecal matter dries and hardens to form the "meconium". As each larva produces only one "meconium" in a cell, the number of "meconia" indicates the number of generations that have been produced in that particular cell, and this fact can be used to determine the total number of wasps produced in a nest throughout the season.

Imms (1938) considers that the period for egg to emergence for *Vespula* sp. varies from four to six weeks, while Duncan (1939) states that, "Du

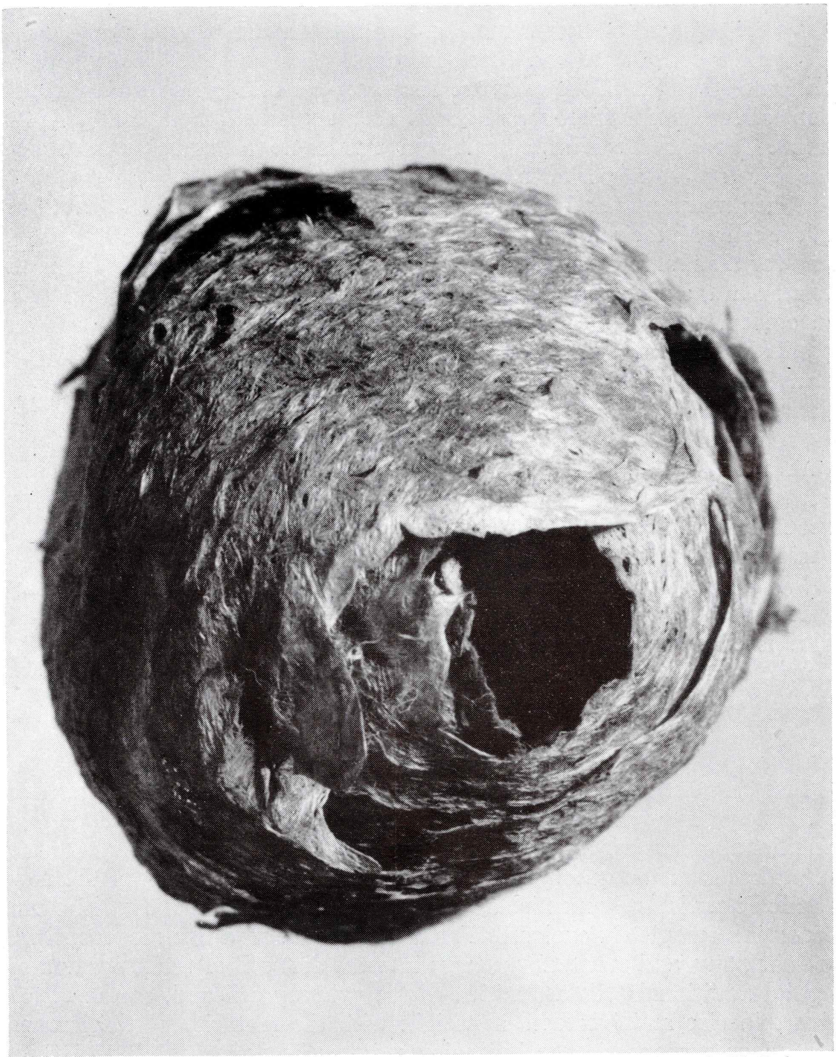

Photo: J. W. Endt

Fig. 13—Basal view of queen nest (fig. 12)

Buysson gives from 12–18 days for the development of a queen larva, about 15 days for that of a male larva, and in the summer season, considerably less for the worker. The length of the larval stage must certainly vary, however, with the species and with the ecological conditions under which the individual colonies develop. Du Buysson considers the pupal stage is approximately 12 days at the height of the season, being the same for all three castes."

It has not been possible to observe the egg to adult cycle *in situ*, and portions of nests kept caged under artificial conditions gave anomalous results. When nests are removed to the laboratory the larvae starve, and, if sufficiently mature, react by pupating. Again, in the ground the combs are almost totally enclosed with paper and comparatively high temperatures are maintained by the metabolism of the insects themselves. This is in marked contrast to conditions in cages, where, to allow direct observation of the combs, the nests are dissected, permitting free movement of cool air. This considerably prolongs the successive stages from egg to adult. Consequently it has not yet been practicable to determine accurately the developmental period of the pre-adult stages.

When mature, the adult wasps emerge by tearing away the silken floor of the cell with their mandibles. Emergence is completed within 30 minutes, and for the first few days of adult existence the newly emerged individuals remain in the nest. They are rather sluggish in their movements and pale in colour, being covered with a dense greyish pubescence. The latter gradually darkens and much of it is shed, the pigmentation of the whole body becoming more pronounced. Soon the workers are ready to go on their first hunting flights.

At first the young worker unsteadily ascends and flies in a small circle within a few feet of the nest. This is repeated several times, on each occasion the circle becoming wider and wider until quite extensive flights become regular and the worker now joins the band of foragers in its various duties.

When the first workers mature the queen relinquishes all tasks save that of egg laying. The workers excavate the soil as the nest grows. Much fibre is collected and added to the nest covering, and the nest takes its characteristic shape (figs. 14 and 15).

DEVELOPMENT OF THE NEST

Few cells are added by the workers to the original queen comb, which ultimately rarely exceeds 4 in. in diameter, but as the season progresses additional combs are added (figs. 16 and 17). First, the walls of one of the central cells of the queen comb are prepared for attachment of the new comb. Paper is finely masticated and plastered to the walls, the cell often becoming completely enclosed. From this base a cord-like suspensorium is built down and eventually merges into the first cell of the lower comb. Again, additional cells are added to the primary cell and, as the comb grows in size and increases in weight with the maturity of the larvae, secondary suspensoria are built down from the upper comb and then reinforced, becoming stout, strap-like pillars. The length of a suspensorium

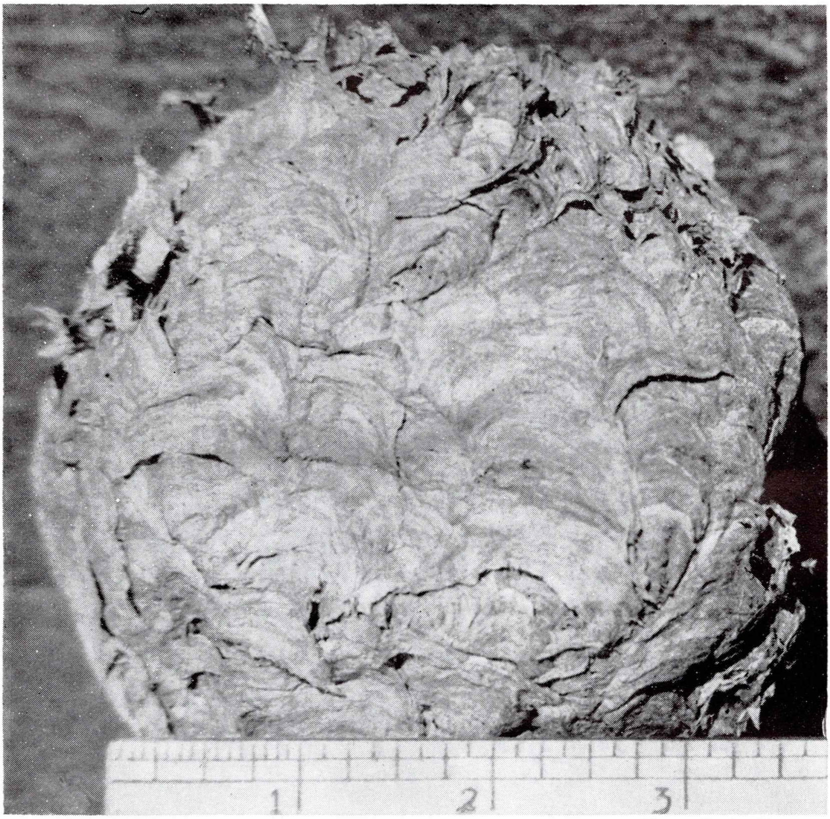

Photo: C. R. Thomas

Fig. 14—Young nest of *V. germanica*

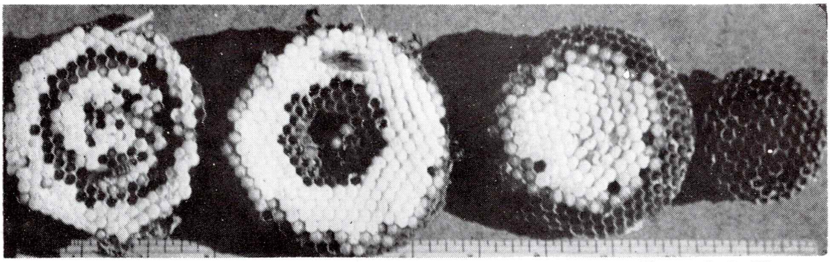

Photo: C. R. Thomas

Fig. 15—Combs of young nest (fig. 14), with queen comb on the extreme left

is such that there is only sufficient room for the passage of the workers between combs. Often combs may be started from several distinct centres at different levels, resulting in the nest becoming irregular, with small combs interposed between the larger ones (figs. 18 and 19).

As the weight of the nest increases additional suspensoria are built above the queen comb, the apical part of the envelope becoming much thickened and dome-like. Mr E. Hall reports finding quite a small nest of *Vespula*

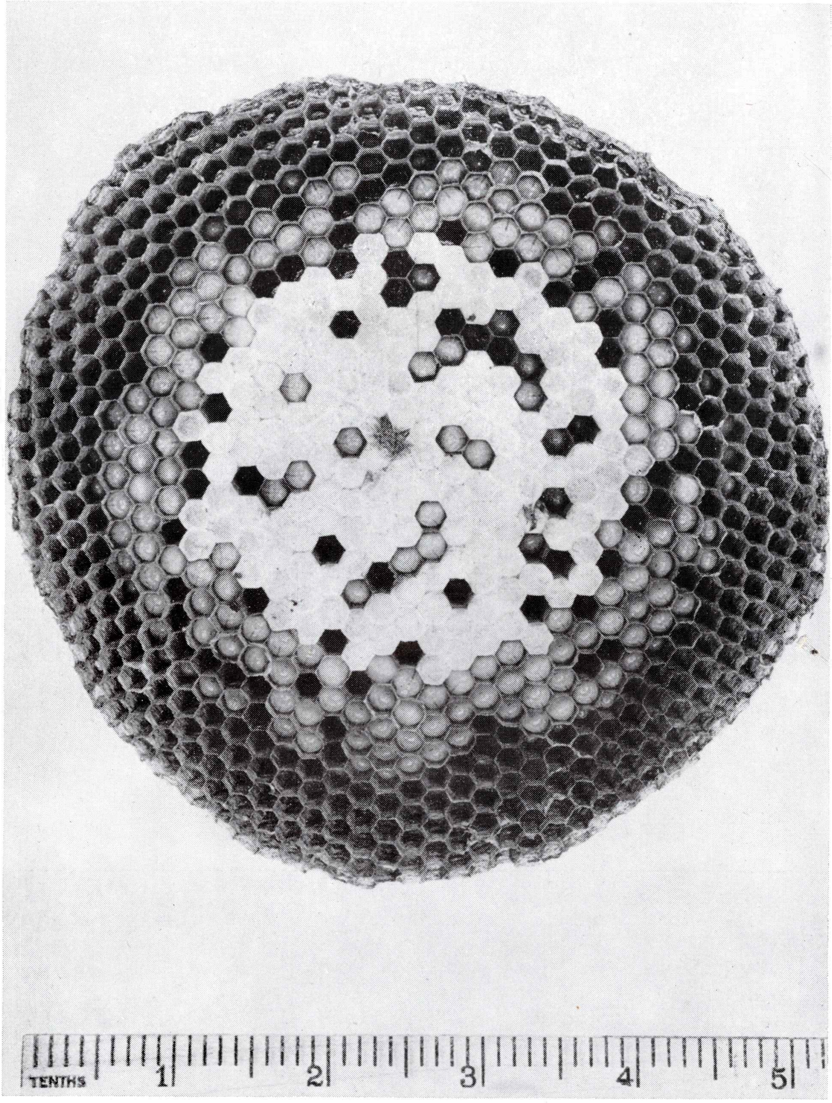

Photo: S. A. Rumsey

Fig. 16—Basal view of typical worker brood comb of *V. germanica:* note successive zones of pupae, mature larvae, and eggs of first generation

germanica lying at the bottom of a nest cavity over 3 ft deep. Presumably the nest had been poorly attached to the roof of the cavity and, with increase in weight, had fallen to the bottom. Although the workers had contined to excavate the earth beneath the nest, the latter had continued to settle, preventing the attachment of more comb layers.

The distance between envelope and excavated cavity walls is almost negligible in the upper part of the mature nest where excavation is no

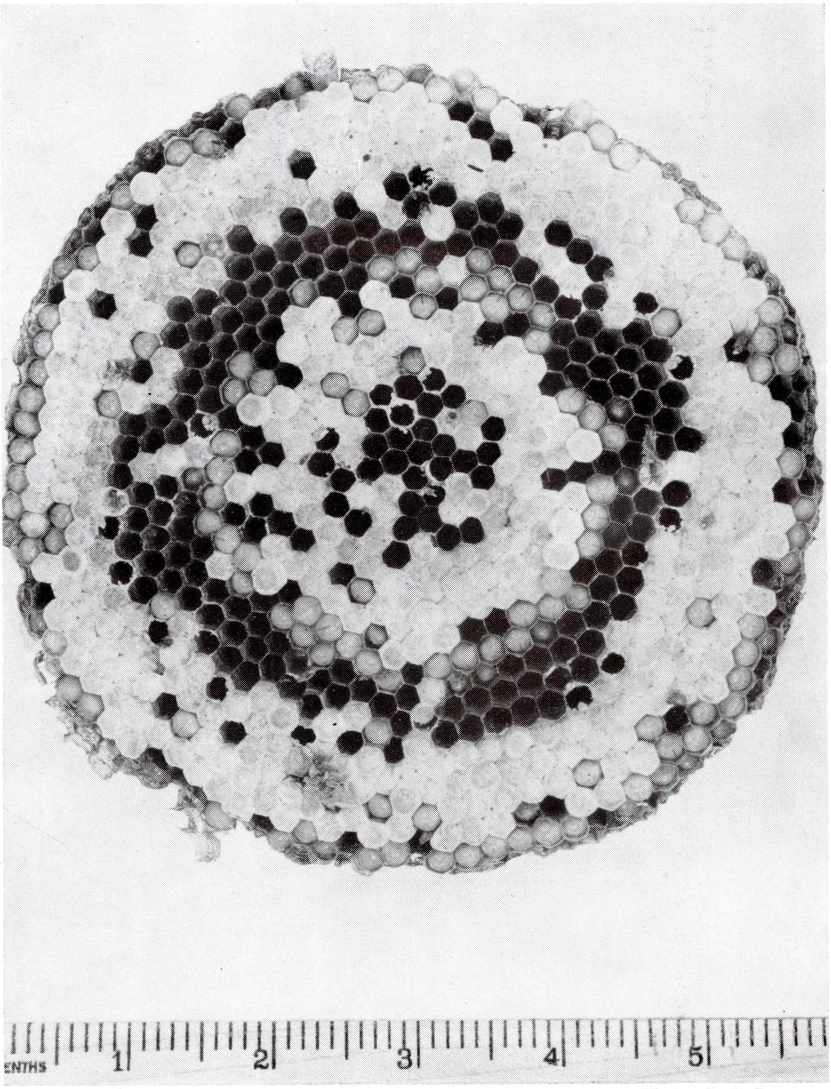

Photo: S. A. Rumsey

Fig. 17—Basal view of typical worker brood comb of *V. germanica*. The central core of cells contains eggs of the third generation. Note ragged edges of some cells from which worker wasps have just emerged.

longer proceeding, while at the base, where excavation is rapid, upwards of 1 in. clearance is left.

The envelope consists of many porus layers of paper bonded together in a manner that makes its enlargement possible without decrease in strength or loss of insulation. The individual crescents of paper can be likened to a cockle shell, the growth lines of which correspond to the successive strips of paper laid down by the workers (fig. 20).

The advantages of this cell-like construction of the nest envelope are obvious. As enlargement of the outer covering proceeds the continuity of the wall is unbroken, and instead of a single layer being removed internally, two portions of adjacent layers are removed to expose a new cavity. As this tearing down of the envelope walls is occurring, building up of the outer layers is continuing. This cell-like pattern may be lost in the upper portions of the envelope where enlargement has ceased, but it is well marked basally. The envelope reaches its greatest thickness in the lower end, thinning out and becoming more compacted where it encloses the older combs. Except in the upper part of the nest the brood combs are free of the envelope, which hangs as a bag surrounding the combs.

The nest entrance through the envelope is very variable in shape. Often it is merely a ragged hole approximately one-third the length of the nest from the apex, while a well plastered, keyhole-shaped entrance is equally as common (fig. 21).

OTHER ACTIVITIES OF THE WORKERS

Apart from the construction of the envelope and nest supports and the collection of food and water already described, activities of the workers include the construction and maintenance of the brood combs and the

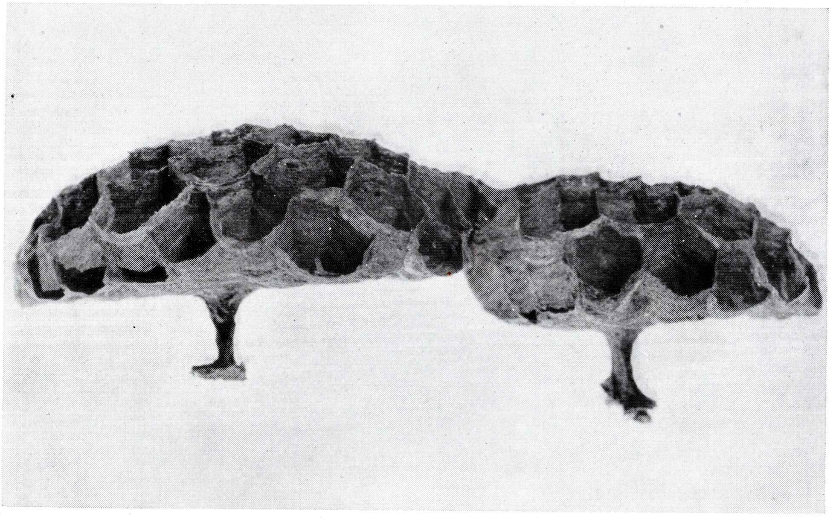

Fig. 18—Worker brood comb of *V. germanica* showing two distinct parts and suspensoria

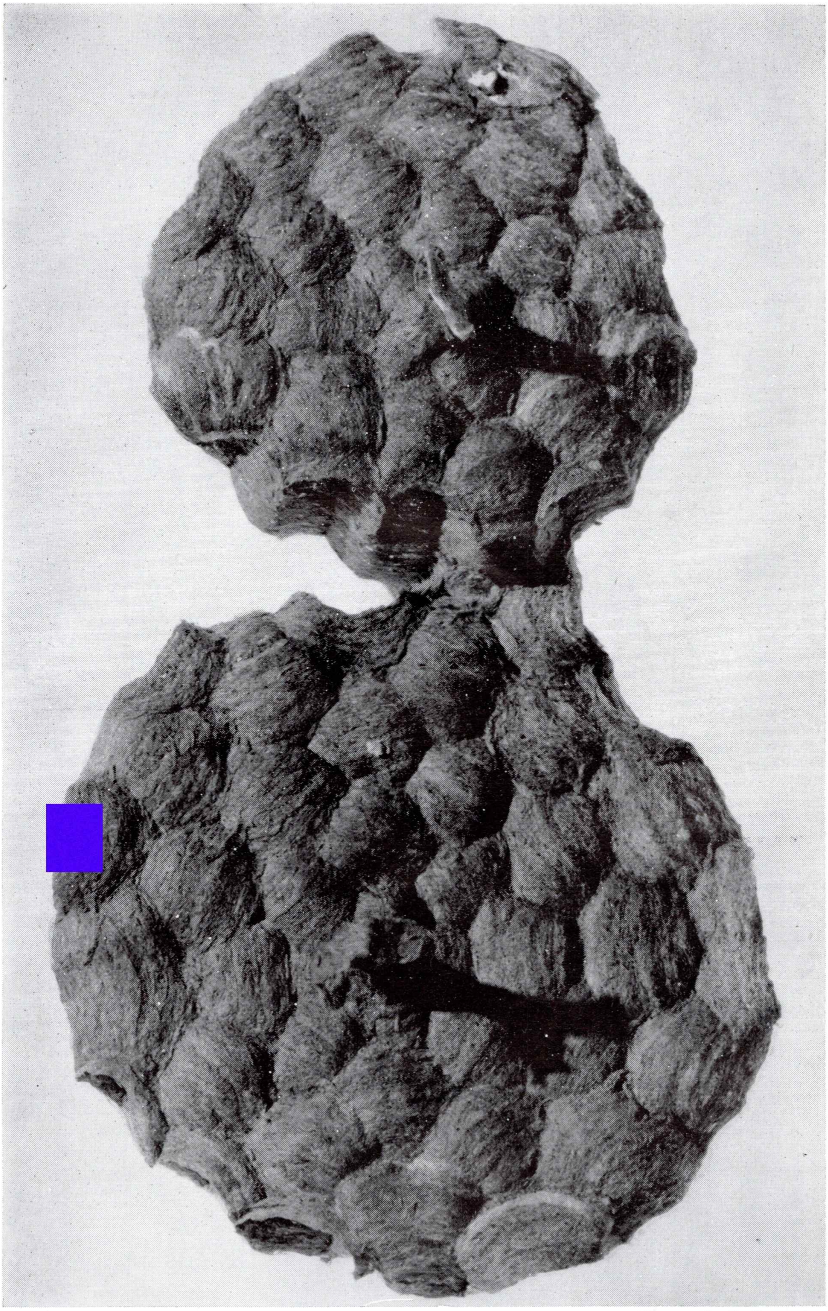

Photo: S. A. Rumsey

Fig. 19—Plan of fig. 18: Note the individual strips of paper

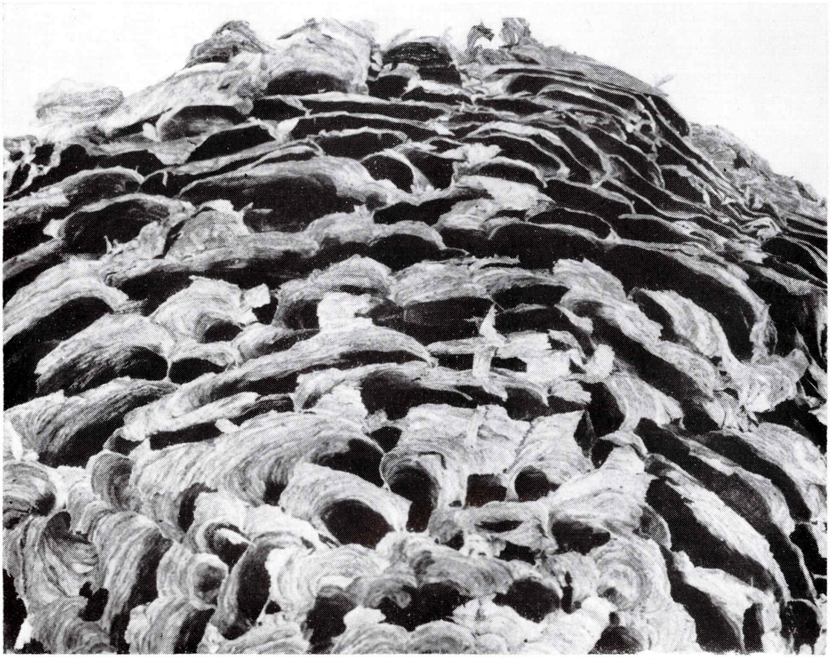

Photo: S. A. Rumsey

Fig. 20—Transverse section of lower outer covering of *V. germanica* nest

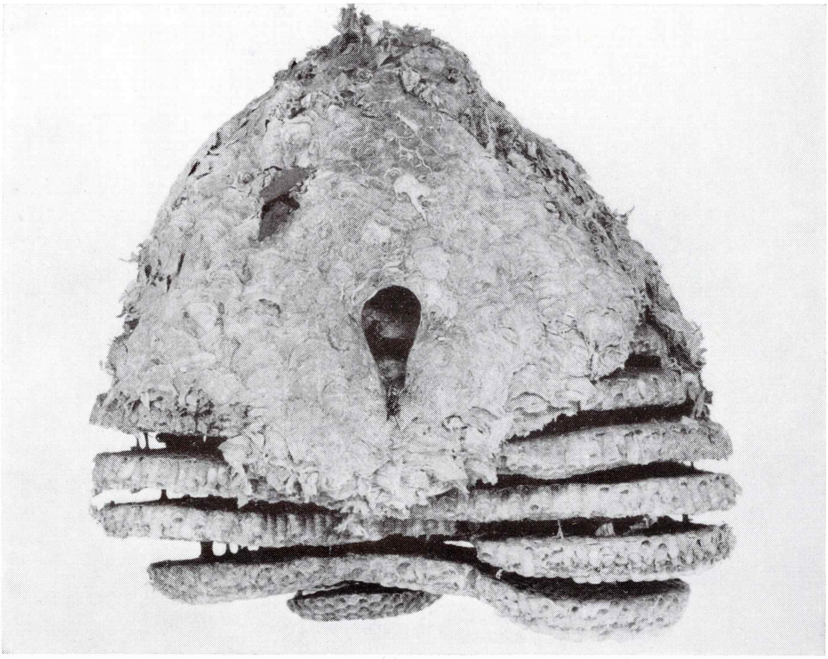

Photo: S. A. Rumsey

Fig. 21—Elevation of typical nest of *V. germanica*. Note prominent entrance. Lower portion of envelope removed

maintenance of hygiene in the nest. Work on the brood combs and suspensoria appears to be the duty of a certain class of individuals, possibly the newly emerged adults which do not forage. The fibre utilised in the construction of the combs is torn from the inner walls of the envelope and as it is again masticated the resulting texture of the combs is much finer and stronger than that of the envelope itself. The paper is laid down in horizontal strips kneaded to conform with the shape of the cells, and securely fixed with saliva.

These workers also trim the walls of each brood cell after the adult wasps emerge, and cut down the cell walls of older combs that will not be used again, to obtain paper for the construction of new cells in the lower part of the nest. Dead larvae are dragged from their cells and carried out of the nest by the workers. Fragments of insect prey, such as legs and wings, are merely brushed from the combs and fall to the bottom of the nest envelope.

DRONE PRODUCTION

In normal single-season nests, mature drones have been found as early as 14 February. They continue to emerge until late May or June. Drones also have been found in overwintering nests throughout the year. The production of drones appears to be independent of weather conditions and is a developmental phase of the colony cycle instituted either by a change in the fertility of the queen or in the larva-adult ratio.

The proportion of males to workers in a nest varies greatly, but when the nest population is greatest drones usually slightly outnumber the workers. As drones do not forage until the demise of the colony approaches, extreme demands are made upon the foraging workers to feed the drones and the teneral individuals of the nest. It is at this time that workers become a nuisance because of their fondness for sweets. This was particularly evident at Clevedon during the summer of 1950. Wasps had not been observed feeding on sweets prior to 14 February, when many workers were seen gathering honeydew produced by *Eriococcus coriaceous* on gum trees. When their nest was destroyed it contained several hundred newly emerged drones. The owner of the adjacent property remarked that the wasps had only been seen feeding on the honeydew over the past few days, that is, at a time coinciding with the emergence of the first drones. Other observations also suggest that the sudden desire for sweets is not initiated by differential feeding of the larvae, but rather by the need to maintain the rapidly emerging drone population.

During the summer of 1950 a nest of *Vespula germanica* was transferred to an observation cage and the mother queen removed. Within seven days the workers were foraging quite normally and continued to do so for nearly three months. The nest was then gassed and dissected. By this time the worker force had become greatly reduced, but drones were numerous in the nest. Although brood production had declined markedly, nevertheless eggs, larvae, and pupae were all present. On examination the pupae proved to be drones. This observation establishes that, under certain circumstances, some workers are capable of producing drone

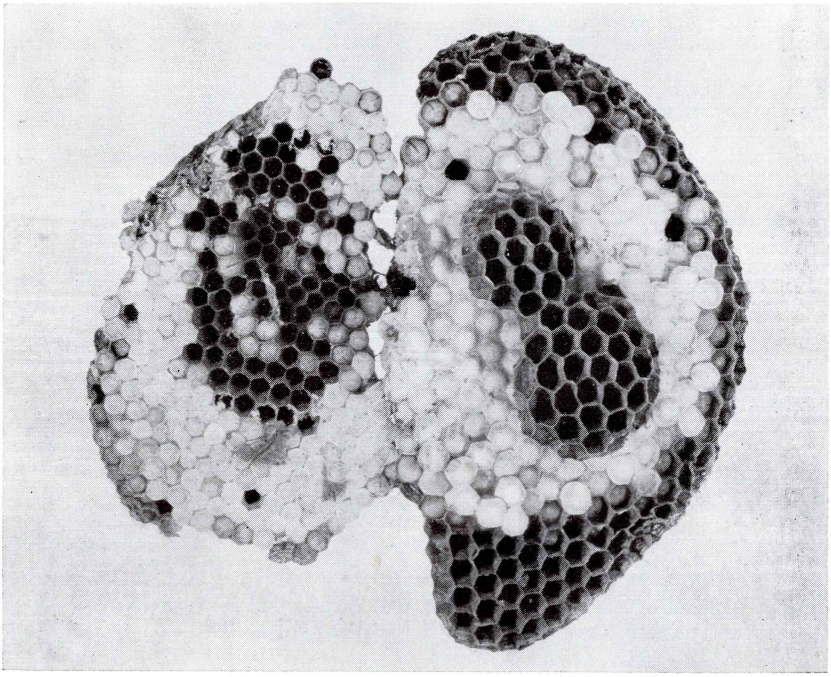

Photo: S. A. Rumsey

Fig. 22—Basal view of two adjacent brood combs of *V. germanica* begun at same level: drone brood on left; queen brood on right

eggs; but whether or not workers are responsible for all the drones in a normal nest is uncertain.

Duncan (1939) states, "As the demise of the colony approaches the eggs laid by the queen cease to produce workers but begin to yield males . . . The males are commonly said to be developed from unfertilised eggs (Lubbock; Wheeler; and others) but the mechanism which determines that some eggs shall be fertilised and others not remains yet to be discovered." However, the fact remains that no really satisfactory explanation has been forthcoming to account for the manner in which fertile or unfertilised eggs are laid, apparently at will, by the queen. Nor does Duncan (1939) offer any evidence that the queen is responsible for the drone eggs. An alternative explanation is that drone-producing eggs are laid entirely by the workers, even in nests containing a functional queen. So far only those drones produced in cells similar to those in which the workers are bred have been discussed. These are the drones, produced in large numbers in late summer and early autumn, which later mate with the virgin queens.

In addition, in late May and June, in some nests drones are raised in the large cells primarily constructed for queen brood. These drones, which rarely exceed 100 in number, have not been observed to mate. Probably they are unable to do so because of their large size. These large drones possibly develop from unfertilised eggs laid by the queen following exhaustion of sperm in the spermathecae.

QUEEN PRODUCTION

From an examination of many nests dissected during three seasons it appears that the change from drone to queen production is abrupt. Often combs started as drone combs are later modified for the rearing of queen brood. The changeover appears to be in part initiated by the first winter frosts (fig. 22).

On 14 March 1950, shortly after a succession of three heavy frosts, the first of the season, four nests were dissected. In each the construction of queen cells had only just begun. A similar observation was made during 1951.

Queens are also produced throughout the winter in overwintering nests, and with the onset of warm spring weather workers are again produced. It is a popular belief that queens are produced only when food becomes especially abundant, but normally queen production does not begin until late March or April, a time when the quantity of available food is declining markedly. Further queen production in overwintering nests cannot be explained by an abundance of food, but is possibly a response to adverse conditions.

MATING

Although there are observations of mating made on caged individuals of other Vespine wasps (Gaul, 1942), there are apparently no recorded observations of the mating habits of *V. germanica.* Mating flights are often seen in New Zealand.

Following the maturity of the drones and queens, usually in late April and May, mating occurs. Mating flights have been observed as early as 16 March and are commonly seen on fine days throughout the early winter. Wasps from overwintering nests have also been observed mating in late October and mid January.

Mating occurs only on warm, fine days. In mid morning the mature drones leave the nest and congregate about the tops of nearby shrubs or trees, flying ceaselessly in a series of figure-eights. The presence of wasps in such large numbers has often given the impression that the wasps were swarming.

The mature queens now leave the nest. Prior to mating, the queen alights on a leaf or branch of a shrub or tree. Almost immediately the drones attempt to copulate. Three or four drones may be attracted to the one queen, but in the field only one appears to copulate, the others being rejected. Drones often attempt to copulate with drones that have successfully mated with a queen. This suggests that the queen attracts the drones with a scent, and that once drones have become contaminated with the odour they are themselves attractive to other drones.

Mating will also occur in quite small cages. On one occasion four drones were seen to copulate with a queen within 20 minutes. Although there were many other queens of comparable age in the cage at this time, only three were attracting drones.

In the field mating has been observed only between drones and queens from the same nest, but there is no reason to believe that this is always so. Whether or not mating takes place in the nest during periods of continued unfavourable weather is not known.

Prior to copulation, which usually is accomplished in less than five minutes, the drone alights on the back of the queen and firmly grasps her thorax with the fore legs. The drone strongly arches his body, gradually working back nearer the abdomen of the queen. Within a short time the drone grasps the queen firmly in his claspers and penetration is effected. Often the drone will relinquish his hold of the queen and, held by the claspers and penis alone, hang upside down below her. If disturbed both queen and drone are capable of flying sluggishly in this position, but after travelling a few yards become exhausted.

After mating, queens and drones return to the nest for a short time. Queens have not been observed to feed after mating, and the evidence suggests that hibernation takes place almost immediately.

THE DECLINE OF THE COLONY

Following mating of the queens there is a marked reduction in activity of the parent colony. Workers no longer return promptly to the nest with food for the larvae, but stay out for successively longer periods, gorging themselves on any suitable food, which by this time of the year is usually becoming scarce. The drones can no longer rely on the workers for food and must forage for themselves. Many drones fail to return to the nest and, as the worker force rapidly diminishes, cannibalism begins in the colony, the spent mother queen eventually being a victim. The few remaining workers drag the larvae from their cells, and after imbibing the body juices they carry the mashed larvae from the nest. The silken caps covering the pupae are torn away and the pupae treated in a like manner. Within a few days the nest is completely vacated. Then mice and rats complete its destruction.

Thus by either late May or June, in the normal course of events, the species is once more represented solely by hibernating queens.

SIZE OF NESTS

In New Zealand, particularly in the Waikato where many of the river-derived soils are only poorly compacted and can readily be excavated, large nests are quite common. Indeed, the average size of nests of *V. germanica* found in New Zealand appears to be considerably larger than is common overseas.

In a typical nest shown in fig. 23, queen production had not begun when the nest was dug up. However, its length was 21 in. and diameter, 14 in. with 18 comb levels.

What is probably the largest single-season subterranean nest yet found in New Zealand was discovered in the grounds of the Waikato Hospital. It was nearly 4 ft long and about 18 in. across. The number of comb levels was not recorded. Aerial nests of this size are quite common, however, due to the absence of obstacles restricting enlargement of the nest.

POPULATION OF NESTS

On 31 March 1949 a nest of *V. germanica* slightly smaller than that shown in fig. 23 was removed from a clay bank at Clevedon. Queen cells had only just been started. The actual count of adult wasps of the three castes was:

Queen	1
Workers	5,709
Drones	6,231
Total	11,941

Owing to the difficulty in removing the nest a few workers and drones remained uncollected.

Later in the same season a comparatively large nest still in a process of rapid enlargement was discovered at Papakura. This nest had 17 combs, of which the two lowermost (combs 16 and 17) were queen combs. Comb 15, although started as a worker comb, had queen cells built around its margins and two small lobes of queen cells had been attached to comb 14. In all there were 3,339 queen cells, approximately 500 of which contained eggs of the second generation.

Mr E. Hall reports finding a nest that contained approximately 6,000 queen cells, but does not give any information on the number of generations bred from these.

In midwinter, on 28 July 1951, a large overwintering nest from the grounds of the Plant Diseases Division was dissected. The nest was very dilapidated and would probably have survived for only a few more weeks.

A count of the occupants gave:

Queens	41
Drones	276
Workers	275

Between the upper combs of this nest 24 hibernating queens were found.

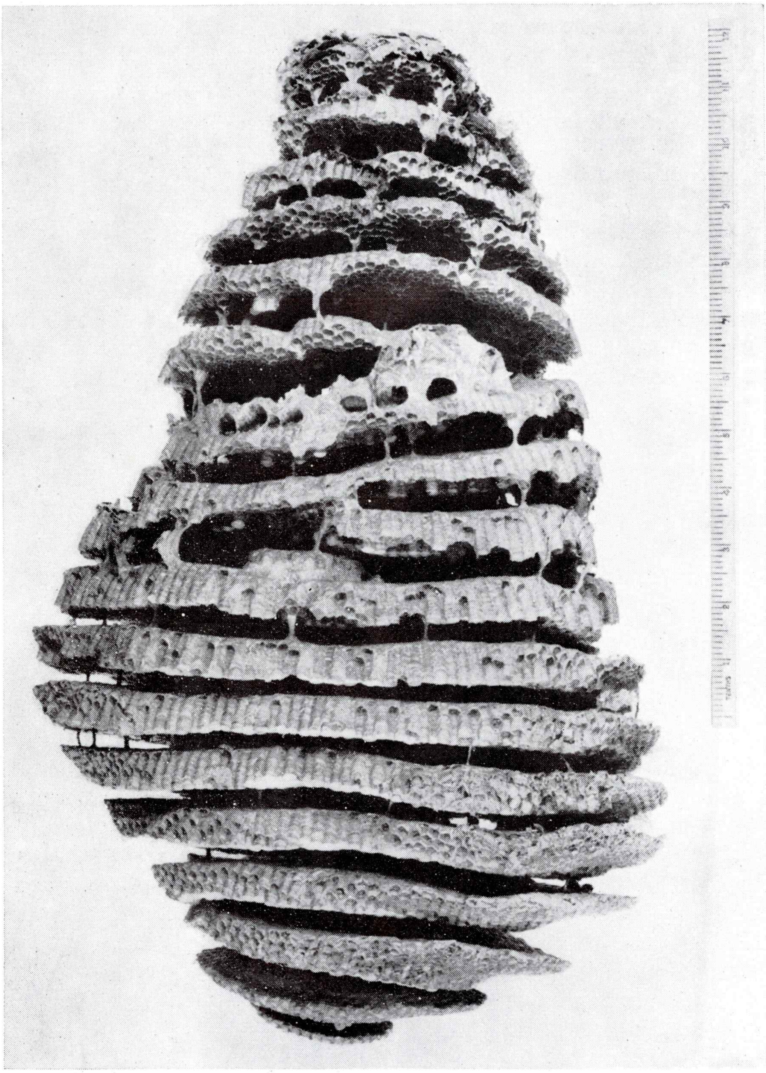

Photo: S. A. Rumsey

Fig. 23—Typical nest of *V. germanica:* envelope removed

OVERWINTERING OF COLONIES

Undoubtedly frosts are primarily responsible for starting the decline of the colonies. This is substantiated by the fact that in areas comparatively free from frosts many wasp nests overwinter. The majority of these overwintering nests appear to have been started comparatively late in the season, and in these nests queen brood production has barely begun when other colonies are beginning to decline. However, nests begun early in the season have been known to overwinter.

The proportion of nests overwintering is very variable, depending on the severity of the winter months and, to a lesser extent, on the availability of food. During the mild winter of 1948 many nests overwintered. The wasps from these nests robbed many beehives of their winter stores, and as a result many bee colonies were lost through starvation.

On 12 October 1949 a typical overwintering nest of *V. germanica* was discovered in Hamilton. When dissected, the distribution of the brood was found to be as follows:

Comb

1. Original queen comb. Empty and sealed off around margins from the lower combs.
2. Excepting about 50 cells, all of which were empty, this comb was completely papered over.
3. Almost empty, with a marginal zone of worker pupae.
4. Completely filled with worker and drone brood—mostly mature lavae.
5. A mixed worker and drone comb of mostly mature larvae and pupae with a few eggs.
6. A large comb. A central core of queen cells containing mostly mature larvae and pupae with very few eggs occupied over half the comb. Normal drone and worker brood (mostly pupae) was present in the outer cells.
7. Similar to 6. Queen cells mostly with pupae. Distinct zoning of two generations of worker and drone cells.
8. A large bilobed comb. A central core of queen cells occupied two-thirds of the area. Zoning of the queen brood was very marked, the central cells containing mature larvae, these surrounding and merging into cells containing eggs and then a wider zone of queen pupae. The outer worker and drone brood showed, passing successively outward: mature larvae, eggs, pupae, mature larvae, and eggs.
9. A large bilobed comb with a central core of empty queen cells, then a zone of queen pupae surrounded by worker and drone cells of two distinct ages.

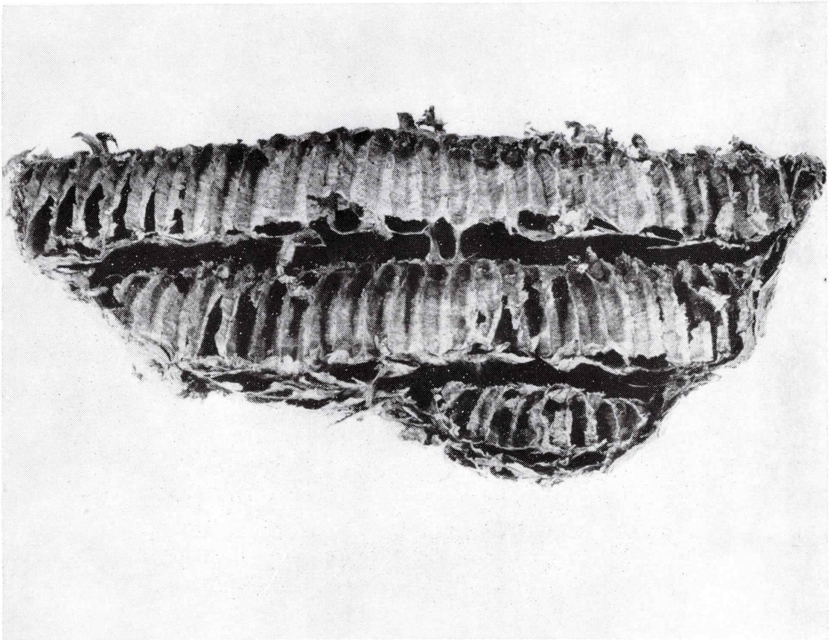

Photo: S. A. Rumsey

Fig. 24—Longitudinal section of three bottom combs of an overwintering nest of *V. germanica*: note how they have been sealed off from combs above

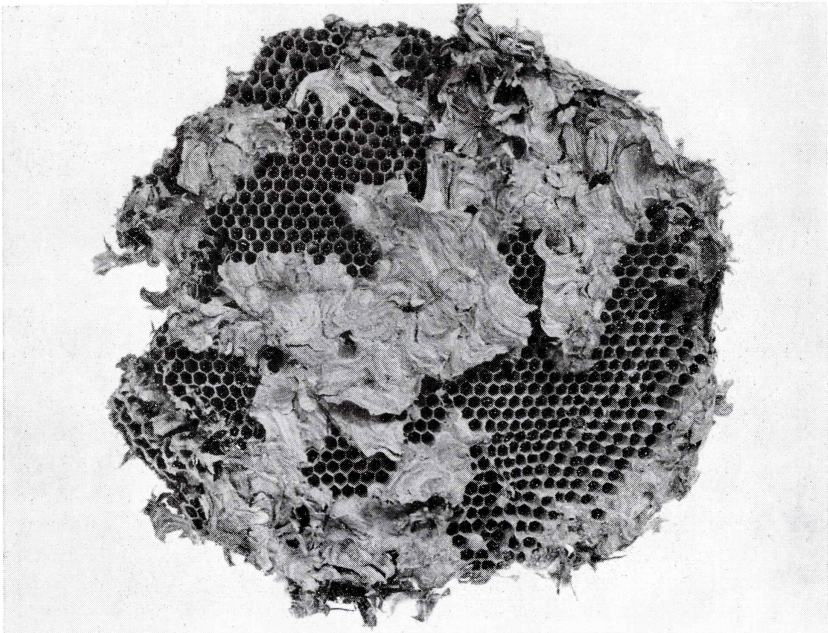

Photo: S. A. Rumsey

Fig. 25—"Sheet" enclosing of an old comb from an overwintering nest

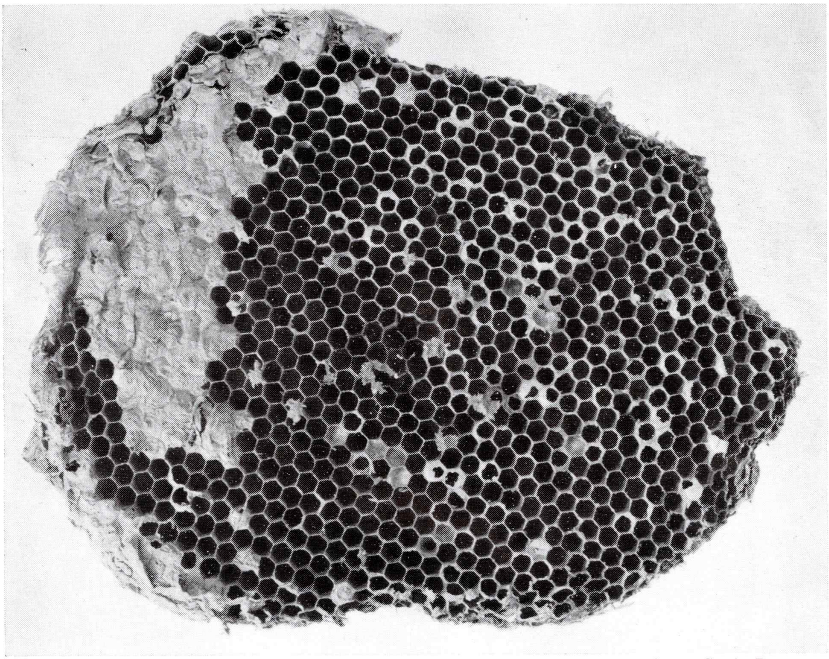

Photo: S. A. Rumsey

Fig. 26—"Cellular" enclosing of an old comb from an overwintering nest

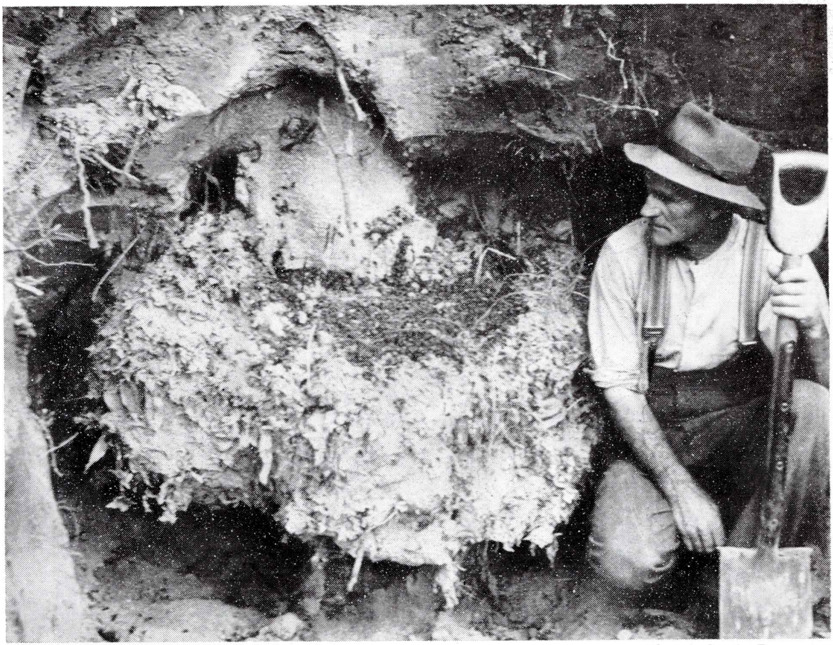

Photo: S. A. Rumsey

Fig. 27—Large subterranean nest of *V. germanica* discovered at Te Awamutu on 8 November 1949: measurements: 47 in. wide, 40 in. high, and 38 in. deep

10. A large comb with a central core of queen pupae surrounded by a narrow zone of mature queen larvae. Enclosing the queen cells were four concentric zones of worker brood, in succession: eggs, pupae, mature larvae, and eggs.
11. Similar to 10 with a central core of hatched queen cells.
12. }
13. } Both consisting entirely of concentric zones of worker brood.

Many other nests similar to the above have been dissected. They have the following characteristics:

(a) Unused combs are sealed off, possibly in an attempt to increase the nest insulation (fig. 24);
(b) Many cells are sealed with circles of paper (figs. 25 and 26);
(c) Brood production is much less than in a summer nest;
(d) The majority of brood produced throughout the winter is queen brood;
(e) With the onset of warm spring weather, production of the worker caste is resumed.

Sometimes colonies which have survived the winter will complete a second season. Workers are produced throughout the spring and early summer and a second generation of drones and queens may be produced in the late autumn. Such nests reach comparatively enormous proportions, particularly if built in aerial situations. Although none of the many large nests observed by the author were more than 18 months' old, it seems possible that nests in extremely favourable locations might continue for three or even four successive seasons.

Probably one of the largest subterranean nests of *V. germanica* ever discovered was found on 8 November 1949 at Te Awamutu. The colony was kept under observation until 9 February 1950. When the nest was dug out with the envelope, which was up to 9 in. thick in some parts, it measured 47 in. wide by 40 in. high and 38 in. deep, with 27 comb levels, and weighed perhaps 100 lb (fig. 27). Only drones and workers were found in the nest. There were no virgin queens and the queen mother was not recovered. All cells were being used for brood production. The regular pattern of brood succession had been completely lost, the distribution of the different castes in the combs being as follows:

Combs
1–6. Worker Combs;
7–8. Mostly worker brood, but with a core of queen cells containing drone brood;
9–22. Core of queen cells containing drone brood surrounded by worker brood;
23–27. Worker brood.

This indicates that the typical pattern of an overwintering nest had been followed, queens being reared throughout the winter. These cells were surrounded by worker brood when favourable weather prevailed again in the early spring.

Another large overwintered nest was discovered in April 1951 at Makomako, Kawhia. This nest had been started beneath the fork of a

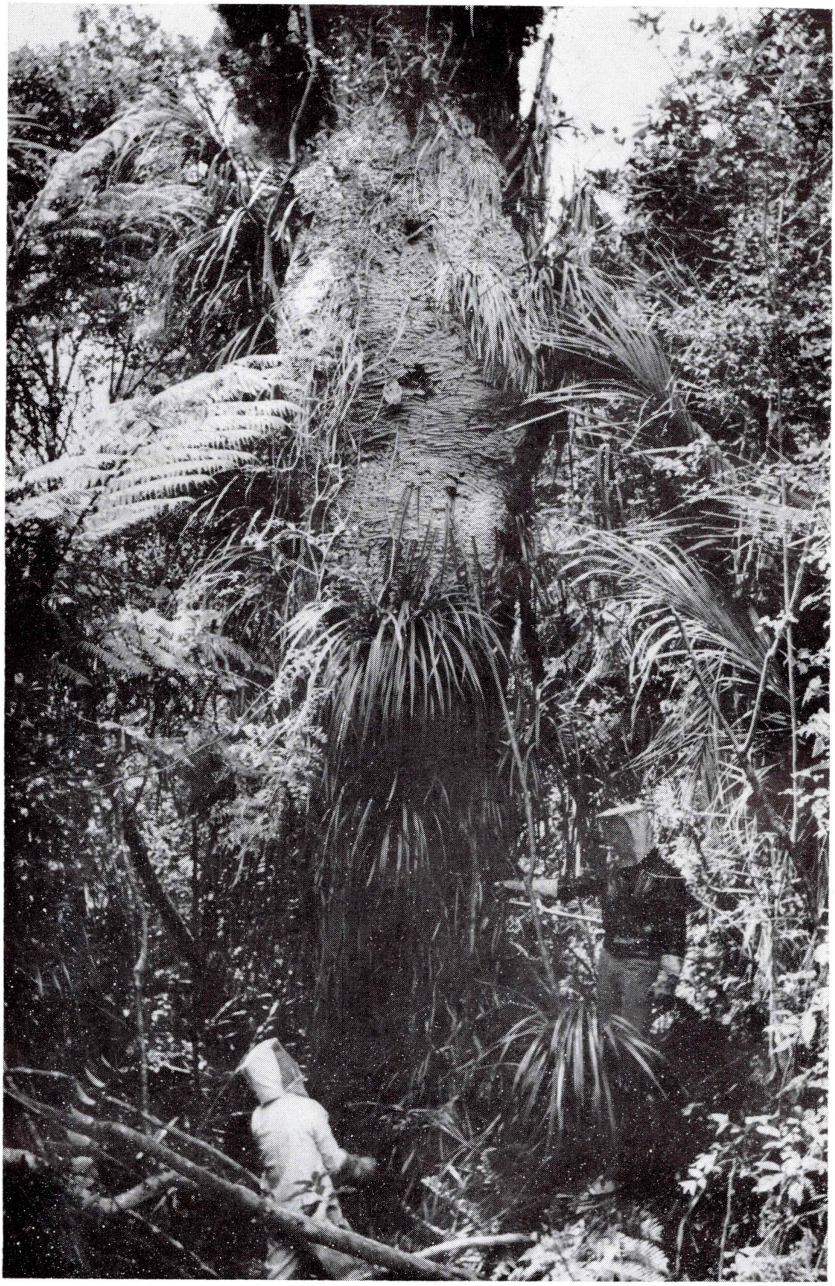

Photo: C. R. Thomas

Fig. 28—Huge nest of *V. germanica* discovered in the Waitakere Ranges. Measurements 14 ft 11 in. × 5 ft × 2 ft: the author is pointing to the lowermost part of the nest

branch of a large kahikatea (*Podocarpus dacrydioides* A. Rich.) overhung with creepers and grass. In an area almost free from frosts, the nest had grown to a length of 8 ft by 4 ft 9 in. wide and approximately 15 ft in girth. The majority of many wasps flying from the nest were drones; no queens were seen.

The largest nest yet discovered was found in dense bush in the Waitakere Ranges on 6 February 1952. It was on a large totara (*Podocarpus totara* A. Cunn.) tree, nearly 20 ft above the ground, and had been started beneath overhanging creepers. When found it measured 15 ft high, 5 ft wide, and was 2 ft thick (fig. 28). The combs, which had been built half way round the trunk of the tree, were traversed by many branches, leaves of epiphytic grasses, and native creepers. When destroyed in late April the colony was still extremely active, over half the flying insects being drones. Unfortunately, because of its inaccessible position, it was impracticable to dissect the nest.

A feature of these two nests was the presence on the ground below of smaller secondary colonies which, being merely irregular masses of paper without brood, continued to operate as separate entities.

Other nests comparable in size to those discussed above have been reported, particularly from heavily bushed areas where aerial nests are common, and from remote areas where the chances of a nest being destroyed in the first season are not very great.

In all the overwintered nests which the author has dissected, only a single functional queen was present, but the possibility remains that some of the first crop of autumn queens may return to the nest and assist in egg laying, since Duncan (1939) records a large nest of *V. vulgaris* in which 22 functional queen mothers were found.

ECONOMIC SIGNIFICANCE

Because of the concern felt by the public in New Zealand and a considerable diversity of opinion overseas, a survey was undertaken in 1949 to attempt to determine the economic importance of *Vespula* in the Waikato. From what is known regarding wasp biology it was obvious that the only possibilities of serious economic damage were attack of ripe fruit in orchards or vineyards and the robbing of honey stores from beehives, and, indeed, no other cases of wasp damage have been reported.

ORCHARDS AND VINEYARDS

From the beginning of the inquiry it was obvious that losses of fruit crops for which wasps could be held primarily responsible were more or less negligible.

Wasps are not attracted to sweets until mid March, and the peak abundance of wasps does not occur until mid April or even as late as mid May. Consequently the fruit industry suffers little from wasp depredations because, of the more important fruit crops, only late apples, pears, and quinces are still unharvested when the wasp population is at a maximum. Further, almost without exception, fruitgrowers in the infested area agreed that wasps are not able to attack sound fruit, although grapes and figs were held to be possible exceptions. Damage to grapes, however, has up to the time of writing been insignificant. One Waikato grower in a particularly heavily infested area estimated his total loss due to wasps as approximately 10 lb of a total yield of 12 tons of grapes. During the 1949 survey not a single case was encountered where commercial orchardists considered loss to exceed 1 per cent of the season's crop of fruit, and it was generally agreed that any loss suffered was of fruit normally sold as "domestic" grade. This fruit is usually damaged by birds, insect pests, diseases, or mechanically, but nonetheless there is a considerable demand for such produce. Secondary attack, arising from wasp attack starting at the site of the various breaks in the skin, renders unsalable a large percentage of such fruit (fig. 29).

Private fruitgrowers may, however, suffer considerable loss. Often no spraying programme is carried out and consequently the fruit is attacked by pests and diseases; also birds are uncontrolled. Furthermore, most of the fruit is left to become overripe on the trees and this also renders it more liable to mechanical damage and to wasp attack. With normal orchard hygiene, however, losses are negligible.

APIARIES

Some beekeepers suffer considerable losses from wasps. Wasps are most numerous towards the end of the honey flow, but even in April and May bees are still sufficiently active to defend the hive. In late May and June, when the hive colonies contract into a small cluster, robbing may become more serious as the hives are then only poorly defended and wasps enter readily to rob honey from the outer frames. Thus autumn-reared nuclei are especially liable to attack and many have been completely robbed out. By contracting the hive entrance to a three or four beeway the bees are better able to guard the hive, but even this will not prevent persistent robbing.

In most seasons frosts in late April and May reduce the wasp population to an insignificant level and terminate the robbing, but in mild winters, such as that of 1949, many wasp nests overwinter and drones and workers from these prove a serious menace, even into September and October. In that year over 60 established hives in the Waikato were known to have been lost and undoubtedly others suffered the same fate. These known losses included an apiary of 34 hives, all of which were completely robbed out. In this case, however, robbing by bees from an adjacent apiary and

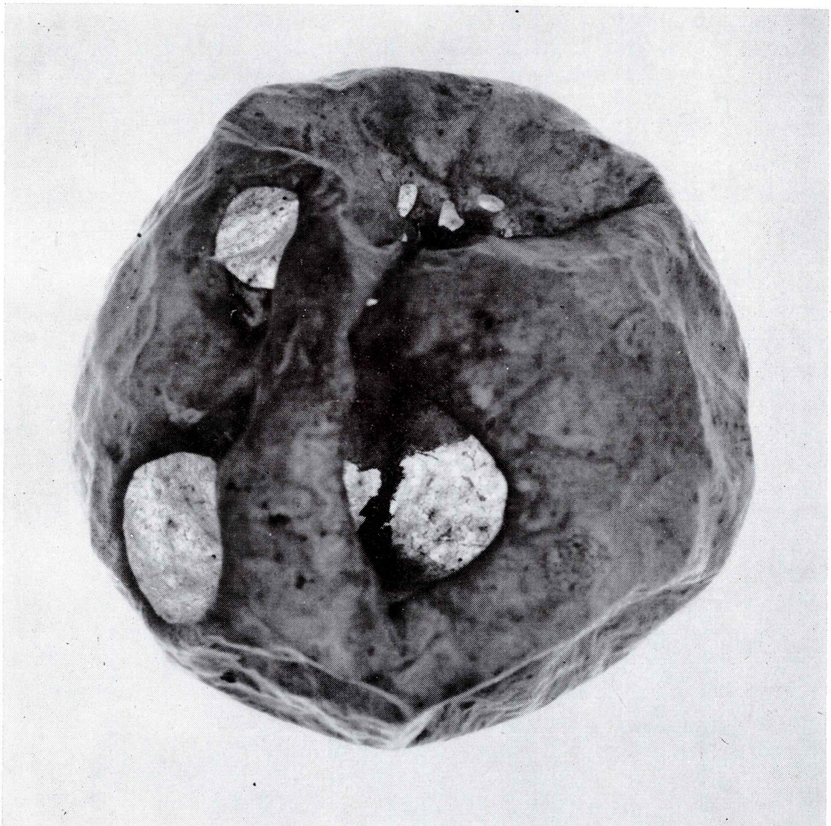

Photo: S. A. Rumsey

Fig. 29—Typical damage to an apple by *V. germanica* following attack by birds: the fruit has been completely hollowed out, leaving only skin and core

the fact that the hives had been left rather "light" in winter stores accelerated the starvation of the colonies.

The actual loss of winter feed from hives in areas with heavy wasp infestation was investigated in the autumn of 1950. Four apiaries suitable for the observation were selected within a radius of approximately ten miles. They were:

(1) *Te Rapa*—Robbing by wasps was of only minor extent as very few nests overwintered in this locality.

(2) *Kaipaki*—Because robbing had been serious in the previous winter in this apiary the owner spent a considerable time in the late summer of 1950 eliminating wasp nests within flying range of his apiary. Fourteen nests had been located and destroyed and, as a result, the area around the apiary was relatively wasp free.

(3) *Tamahere*—This was the site of the apiary of 34 hives that was completely robbed out in 1949. No attempt had been made by the beekeeper to locate wasp nests in the surrounding gullies, but subsequently a search was made and within 10 minutes four large nests were located within 50 yd of the apiary.

(4) *Hillcrest*—This area was completely free of wasps and was used as a control. Weekly weighings of selected hives were made at each apiary from 8 June 1952 to 10 October 1952 inclusive (table 9). Autumn-reared nuclei were also weighed at Te Rapa and Hillcrest and in each apiary regular inspections of the hive colonies were made.

The decrease in weight of hives can be attributed to several causes, namely, depletion of honey stores, falling off in a brood production, and death of field bees. When comparing figures obtained from different apiaries it must be appreciated that shelter of hives and local climatic conditions have a marked influence on the consumption of winter stores. Well sheltered hives consume less honey than hives in an apiary exposed to the weather. Likewise, brood rearing may be continued throughout a mild winter in well sheltered areas.

To offset this, however, in exposed sites the bees more readily enter a cluster where food requirements are reduced to a minimum, while in warmer areas, where the bees remain more active, the rate of consumption of winter stores is high. Thus mild winters have an adverse effect upon hives in two ways. Firstly the bees themselves remain more active, consuming greater amounts of honey (which usually cannot be replenished), and secondly the absence of frosts allows many wasp nests to overwinter. In general, decrease in weight of hives due to the death of older bees is so slight that it can be disregarded.

From table 12 it can be appreciated that sometimes losses of winter stores due to robbing by wasps can be considerable. Whereas the average requirements of normal hives in a wasp-free area were 0·85 lb of honey a week, in the badly robbed apiary (apiary No. 3) this average was 3·15 lb. Although such robbing only occurs for a limited period it can involve considerable loss when it is considered that some beekeepers

TABLE 9—AVERAGE WEEKLY WEIGHT OF SELECTED HIVES IN FOUR SEPARATE APIARIES

Date	Apiary No. 1 Te Rapa					Apiary No. 2 Kaipaki			Apiary No. 3 Tamahere					Apiary No. 4 Hillcrest					
Hive No.	1n	2n	3n	1	2	1	2	3	1	2	3	4	5	1n	2n	3n	1	2	3
Original weight (lb) at—																			
8/6/50 ..	21	30	51	170	175	109	144	113·5	104	95	98	116	..	15·5	16	19	103	110	120
15/6/50 ..	21	30	50	169	174·5	107	143	112	101	80	96·5	110·5	..	15·5	16	18	102	109	118·5
22/6/50 ..	20	29·5	49	167	174	105	141	112	98	79	94	105	110	15·5	15	18	100	108·5	118·5
29/6/50 ..	20	29·5	49	168*	172·5	107*	144*	112	96	Colony dead	93	96	108	16*	15·5*	17·5	100	110*	118·5
6/7/50 ..	19	29	48	165	169	105	140	112	95	..	89	88	105	15·5	15·5	18	100	109	116
13/7/50 ..	17·5	27	46	162	168	102	138	109·5	93	..	93‡	92§	104	15·5	15	18	98·5	108	116
20/7/50 ..	17·5	26	44	159	164	101	134	107	90	..	93	85	101	15·5	15	18	96·5	106·5	113
27/7/50 ..	17·5	26	45*	160·5*	164	100·5	135*	109*	88	..	95†	80	100·5	15	15	17·5	96	106	112
3/8/50 ..	17	26	44	160	162	100	132	106	88	..	95	Colony dead	100	15	15	16	95	105	112
10/8/50 ..	17	24	42	158·5	160	..	..	..	88	..	95	..	99	..	..	..	95	104	111
Total loss (lb) ..	4	6	9	11·5	15	9	12	7·5	16	16	13	51	11	0·5	1	3	8	6	9
Average weekly weight decrease in each apiary (lb)	0·70			1·47		1·19			3·15					0·19			0·85		

Hives Nos. 2 and 4 in Apiary No. 3 were completely robbed out.
*Apparent increase due to absorbed water after heavy rain. †Increase due to robbing from overturned hive. ‡10 lb winter feed added to stores. §15 lb winter feed added to stores.

require 10 tons or more of winter feed; even a small percentage increase in this amount involves considerable money.

Wasps rarely attack an apiary indiscriminately. Rather they concentrate on certain hives. These seem to be chosen at random and are not necessarily the weak hives, as is popularly supposed. When robbing first commences the bees endeavour to guard the hive and vigorously attack the wasps. For a short time their defence is completely successful, but persistent attempts overcome them and then wasps freely enter the hive. Once a colony has become demoralised all winter stores may be lost in a month or less. As shown in table 12, 15 lb of honey was lost from one hive in a single week. When all the honey has been removed from a hive the wasps transfer their attention to another hive and in this manner a whole apiary may be robbed out over a period of four to five months, as happened at Tamahere.

In most areas robbing is negligible, but beekeepres with apiaries close to rough gullies or in undeveloped country should be particularly alert when making routine inspections of hives during the late autumn and winter. There is little that can be done to prevent robbing other than the obvious and direct method of locating and destroying all wasp nests within flying range of the apiary, and, indeed, this method can be expected to be completely successful. Severe robbing such as occurred at Tamahere is quite exceptional and results from failure to destroy wasp nests near the apiary.

In any discussion on the economic importance of wasps their beneficial activities must not be overlooked. Many species of harmful insects, particularly flies and caterpillars, are killed by the workers, and it is commonly claimed that there has been a marked decrease in the abundance of blowflies since wasps became established. Indeed, the majority of European entomologists consider the beneficial activities of the wasp far to outweigh any losses for which they may be responsible. Nevertheless wasps are a great nuisance in the autumn, when they develop a desire for sweets. Then they enter dwellings, breweries, honey houses, and, indeed, any place where sweets or fermenting substances are kept or handled. They are also a great nuisance to those picking and handling fruit in the open. As they seldom contaminate or spoil food directly their nuisance value is largely due to the persistence of their search for sweets and the fear persons have of being stung. However, the sting of the wasp is no more to be feared than that of the honey bee and wasps usually will not attack unless provoked in some manner.

CONTROL MEASURES

By 1948 wasps had become so abundant and had spread so rapidly that it seemed desirable to establish adequate control measures in case these should become necessary. Four possible methods of control are discussed below.

DESTRUCTION OF HIBERNATING QUEENS

In the spring of 1948 a bounty of 3d. was paid for every queen sent to the Department of Agriculture. This resulted in over 118,000 queens being collected in less than three months, but, as the following considerations show, it is most unlikely that this destruction of queens made any significant difference to the number of nests established in that year.

An average sized nest of *V. germanica* produces approximately 500 queens. If the same population density is to be maintained from year to year only one queen need establish a nest. Therefore the mortality rate could be 499 in 500, or 99·8 per cent, and as very few queens die in hibernation the mortality of spring queens must be very high. Thus, of the 118,000 queens collected, approximately 250 might have established nests, and this is a very small proportion of the wasp nests in the Waikato.

Obviously control is unlikely to be obtained with such a method, and hence the assiduous destruction of hibernating queens carried on by many amateur gardeners and beekeepers is at best of minor value.

DESTRUCTION OF SPRING QUEENS

Here, as before, control measures must ensure destruction of large numbers of individuals because of the very small percentage which succeed in establishing nests. The following methods were tested:

Insecticidal Treatment of Aphid-infested Oaks

During 1949 large scale spraying of aphid-infested oaks with insecticides was advocated as a control measure for queen wasps (Palmer-Jones *et al.*, 1949). As already discussed (pp. 22–23), in the spring many queens are attracted to the honeydew produced by aphids on oak trees and the method appeared quite feasible. Preparation was made for an experiment involving the spraying of oaks within an area of over 9 square miles. A Buffalo turbine concentrate sprayer capable of spraying to a height of over 40 ft was commissioned for the trial and supplies of colliodal DDT dispersion 50 per cent technical were obtained. However, an inspection of the oaks immediately prior to the start of spraying operations revealed large numbers of honeybees collecting honeydew, and this compelled the abandonment of the experiment.

Because it was desirable to know the possible effects of DDT spraying on both honeybees and wasps, an isolated area comparatively free of honeybees and with eight large aphid-infested oak trees was selected. Four days before spraying commenced, three strong beehives were placed within the group of oaks. Check hives were situated approximately 1 mile away, and although within flying range of the oak trees, the abundance of nectar in the area made it unlikely that bees from the check hives would feed on the sprayed oaks.

When spraying was begun on 15 November 1949, honeydew secretion was at a maximum.

Approximately 4 gallons of spray containing 1·66 lb of 100 per cent DDT was applied to each tree. Because of considerable drift due to wind the tops of the oaks could not be reached, but this may not have been important as most of the honeydew was being excreted on the lower branches.

Three hours after spraying each test hive was weighed and a piece of scrim 4 ft square placed on the ground directly in front of each. By mid December honeydew production had reached such a low level that the bees ceased to work the oaks. Until that time counts were made of the number of dead bees found on the scrim and test hives were weighed at intervals. Results are given in table 10. The differences in the increase of honey stores in the experimental hives are not statistically significant. However, the number of dead bees collected outside the hives working sprayed oaks was significantly higher ($P = \cdot 003$) than outside the check hives (table 10).

Workers from test hive No. 3 did not appear to work the oaks at any time and can be considered as a check. Immediately after application of DDT the field bees from test hive No. 2 were seen working the oaks and in a short time the colony showed obvious signs of distress. Worker bees from test hive No. 1 did not begin collecting honeydew from the oak trees until six days after spraying had been completed. Then the colony became distressed within a short time.

From these results it is apparent that spraying aphid-infested oaks may have a detrimental effect upon adjacent honeybee colonies. However, as the attraction of bees to honeydew is largely determined by seasonal conditions and availability of other sources of nectar, in some seasons spraying of oak trees might possibly be carried out without any detrimental effects on hives. However, it would be almost impossible to predict such conditions, and there would be little point in attempting to do so, for the spraying of aphid-infested oaks cannot be considered seriously as an effective method of reducing wasp populations. It would be costly, and sources of food other than honeydew produced on oak are so abundant in the springtime that only a small percentage of queen wasps could be destroyed.

Artificial Honeydew Experiments

In the spring of 1949 and the following autumn experiments were carried out in an attempt to formulate an artificial honeydew attractive to wasps but not to bees. If such a material could have been produced

TABLE 10—THE EFFECT OF SPRAYING OF APHIS-INFESTED OAK TREES WITH DDT ON THE ACTIVITIES OF TEST BEEHIVES

—	Test Hive No. 1		Test Hive No. 2		Test Hive No. 3†		Check Hive No. 1		Check Hive No. 2		Check Hive No. 3	
Original weight of hive	70 lb		64 lb		86 lb		62 lb		67 lb		78 lb	
Date*	Increase in Weight (lb)	Number of Dead Bees	Increase in Weight (lb)	Number of Dead Bees	Increase in Weight (lb)	Number of Dead Bees	Increase in Weight (lb)	Number of Dead Bees	Increase in Weight (lb)	Number of Dead Bees	Increase in Weight (lb)	Number of Dead Bees
18/11/49	..	58	..	293	..	31	..	19	..	19	..	41
21/11/49	2·5	312	..	99	3	55	..	52	..	14	..	18
24/11/49	1·5	167	1	9	2	6	1	35	4	11	1	31
1/12/49	7	12	..	20	11	34	..	15	15	32	3	33
5/12/49	5	8	..	12	10	18	5	69	3	28	2	34
9/12/49	−1	7	−1	3	−2	6	2	24	2	8	..	15
Total ..	15	564	0	436	24	150	8	214	24	112	6	172

*Oaks sprayed on 15/11/49. †Not working sprayed oaks.

it would have been easy to incorporate an insecticide to destroy the wasps attracted. The trial was a continuation of that begun by Palmer-Jones *et al.* (1949). The composition of the five honeydews tested was as follows:

	Glucose	Sucrose	Dextrin	Water	Remarks
(a)	5	4	1	50	Honeydew developed by Palmer-Jones *et al.*
(b)	8	5	13	50	Approximate constituents of natural honeydew.
(c)	. .	. .	. .	. .	(a) + 10% lactose.
(d)	. .	. .	. .	. .	(a) + 2 oz carbolic acid per gal.
(e)	. .	. .	. .	. .	(b) + 2½ oz meat extract.

The different honeydews were sprayed on to various shrubs within 50 yd of an apiary of approximately 20 beehives as, although spraying would only rarely be carried out so close to an apiary, it was necessary to be certain that the solutions under test were unattractive to bees. In the autumn five wasp nests were artificially established within 50 yd of the above apiary.

Palmer-Jones *et al.* (1949) claimed that solution (a) was only slightly attractive to bees, but in these trials all solutions attracted far more bees than wasps, any temporary absence of bees being caused by worker bees being prevented from foraging by unfavourable weather.

In the spring a few queen wasps and occasional workers (apparently from an overwintering nest) were attracted to the honeydews. In autumn, however, honeydew attracted large numbers of worker wasps. Obviously it would have been extremely difficult to find a material attractive to wasps and not attractive to bees, and the matter was not pursued.

Application of Insecticides to Trees or Shrubs Which Attract Wasps

In late spring, when the sources of nectar available to wasps are somewhat meagre, queens continue to visit some flowers, notably those of *Cotoneaster*, for a considerable time after the bees have ceased to work them. At this time the number of queen wasps is comparatively small and the majority of these have successfully established their nests. Probably this period of nest establishment, extending throughout December, January, and even February, is the most vulnerable in the whole life cycle, and control measures instigated during this period are far more likely to be successful than queen destruction in early spring, when most will die from natural causes in any case. On 15 December 1949, a shrub of *Cotoneaster simonsii* that had ceased to attract honeybees but was still attracting many queen wasps was sprayed with 2 gal DDT solution containing 4 oz. of 50 per cent wettable powder, i.e., 0·625 per cent. Four queen wasps were removed from the flowers of the *Cotoneaster* prior to spraying and four immediately after the spray had dried. Each queen was placed in a jar containing a small amount of honey and the time of death noted.

On 7 December 1950 a similar experiment was performed on a shrub of *C. franchetti*, six queens being removed prior to spraying and six afterwards. Results are given in table 11. In both experiments occasional

TABLE 11—SURVIVAL TIMES OF QUEEN WASPS TAKEN FROM SHRUBS OF *Cotoneaster* SP. SPRAYED WITH DDT

A. 15/12/49 *C. simonsii*

Time Elapsed After Spraying	6 hr	14 hr	38 hr
Check 1	Alive	Alive	Alive
2	,,	,,	,,
3	,,	,,	,,
4	,,	,,	,,
Test 1	Symptoms of poisoning	Dead	Dead
2	,,	,,	,,
3	,,	,,	,,
4	Alive	Alive	Alive

B. 7/12/50 *C. franchetti*

Time Elapsed After Spraying	12 hr	20 hr	30 hr	72 hr
Check 1	Alive	Alive	Alive	Alive
2	,,	,,	,,	Dead
3	,,	,,	,,	Alive
4	,,	,,	,,	Dead
5	,,	,,	,,	Alive
6	,,	,,	,,	,,
Test 1	,,	,,	,,	Dead
2	,,	Dead	Dead	,,
3	,,	,,	,,	,,
4	,,	Alive	Alive	,,
5	,,	,,	,,	Alive
6	,,	,,	Dead	Dead

queens were attracted to the shrubs for the first two days after spraying, but none were attracted after the second day, although many flowers still remained and other shrubs of the same two species in the neighbourhood were attracting many queens. Marked queen wasps have been shown to return repeatedly to a particular source of food. Hence it is presumed that their absence from the *Cotoneaster* following spraying was due to death from DDT poisoning. It is apparent that queen wasps can be killed by the application of DDT to *Cotoneaster* plants after these have ceased to be attractive to bees. However, it is most difficult to gauge the effectiveness of such a method and extreme care would have to be exercised to ensure that honeybees are no longer attracted to the *Cotoneaster* and not merely prevented from foraging by unfavourable weather. Doubtless, in the hands of experienced operators control of wasps by such a means is feasible, but the author hesitates to recommend its general adoption.

Trapping

Trapping has already been discussed (p. 11). It is difficult to assess the degree of control achieved, but in the localities where traps were operated this was never adequate. Doubtless the capture of nesting queens in the late spring and early summer must reduce the number of wasp nests established in an area, but numerous traps baited with highly attractive materials would be necessary as they have to compete with natural sources of food, and the use of such large numbers of traps would probably be uneconomical.

Traps have other disadvantages; they must be rebaited regularly, baits are expensive, and considerable time is required to attend the traps.

DESTRUCTION DURING NESTING PHASE

Treatment of Nests

Destruction of wasp colonies is at present the only effective means of control.

In the autumns of 1950 and 1951 a range of insecticidal preparations was tested to determine which gave most effective control and which could be recommended for general use by the public. To be effective a material should either give a complete kill of all the inhabitants of the nest, e.g., chloropicrin, or should give a rather quick kill of foraging workers, with the residual action of the insecticide persisting for at least three weeks and preferably longer to ensure that wasps emerging after treatment will be killed, e.g. DDT. Further, the methods and equipment used to apply the insecticide should be simple and preferably the insecticide should be non-toxic to human beings and other warm-blooded animals. Finally the insecticide should be reasonably priced.

The procedure followed in carrying out the tests, was that, unless otherwise stated, the insecticide was blown into the entrance of each wasp nest from a short length of ½-in. I.D. rubber tubing in which a measured quantity of the powder had been placed. During application an endeavour was made to obtain complete coverage around the walls of the nest entrance so that all foraging wasps came in contact with the powder when leaving or entering the nest. In the absence of a suitable length of rubber tubing insecticide was applied by what has been popularly called the spoon method. A measured quantity of powder was thrown into the nest entrance from an ordinary dessert-spoon. Good coverage was obtained with this method.

Chloropicrin was injected into the nest entrance by means of a soil injector designed by the Plant Diseases Division (Jacks and Wright). Granular calcium cyanide was thrown into the nest entrance by means of a spoon.

The following insecticides were tested on a total of 200 nests:

1. DDT 10 per cent dust
2. DDT 25 per cent wettable powder
3. DDT 50 per cent wettable powder
4. DDD 25 per cent wettable powder
5. Methoxychlor 50 per cent wettable powder
6. Toxaphene 40 per cent dust

7. Gammexane 2·25 per cent wettable powder
8. Gammexane 6·25 per cent wettable powder
9. Gammexane smoke generators
10. Calcium cyanide
11. Carbon disulphide
12. Chloropicrin
13. Parathion 15 per cent wettable powder
14. Boric acid powder
15. Lead arsenate

Only two of the insecticides, boric acid and lead arsenate, failed to bring about a significant reduction in the strength of the treated wasp colonies.

The DDT powders of 10 per cent, 25 per cent, and 50 per cent concentrations were found to be quick, effective and, for general use, markedly superior to any of the other contact insecticides tested. However, worker wasps contaminated with DDT become exceptionally hostile and it is inadvisable to work near such nests until eight hours have elapsed after treatment. DDD 25 per cent, toxaphene (40 per cent), and methoxychlor (50 per cent) were less effective than DDT. Parathion (15 per cent) gave efficient control but is not recommended because of its high toxicity to man and the hazard to animals foraging near treated nests. Gammexane (2·25 per cent and 6·25 per cent) was markedly slower in action than DDT and appeared to repel worker wasps returning from the field, as they would hover about the nest entrance for a considerable time before entering. Gammexane smoke generators gave rapid control but could only be used in colonies with large entrances.

For general use calcium cyanide was undoubtedly the most suitable of the fumigants tested. It is not recommended as a substitute for DDT but is most useful when immediate cessation of worker activity is essential. However, the immature stages in the nest are not all killed and the young workers emerging after two to three days may revive the nest. Consequently the nest must be dug out and destroyed within 24 hours of being treated or else a second treatment applied approximately three weeks after the first.

Carbon disulphide was far less efficient than calcium cyanide, but if allowed to penetrate throughout the nest and then exploded, could be used at night when the foraging workers had returned.

Chloropicrin gave adequate control, has a rapid action, is long lasting, and no re-treatment of nests is necessary, but it is extremely unpleasant to handle. However, in the hands of an experienced operator equipped with an injection gun, this fumigant should be used in preference to any of the other insecticides tested.

POISON BAIT

A wasp nest must be located before it can be destroyed by dusting or fumigation. This may present some difficulties in rough gullies and uncultivated land, and it may be virtually impossible to find nests in heavy scrub country. Hence, any means by which good control could be achieved without the necessity of actually locating the nest would be useful. Poison baits offer such a possibility. Preliminary work gave encouraging results, but later work showed the method to be of limited value in reducing the wasp population of an area.

For these experiments a solution that has been used successfully against ants in New Zealand was first tried. It was made up as follows:

1·25 lb granulated sugar, 1·25 pt water, 1g tartaric acid, and 1g sodium arsenate were boiled together for 30 minutes.

$\frac{1}{8}$ oz of sodium arsenate was dissolved in 1 fl oz of hot water.

When the two solutions had cooled the arsenate was added to the sugar mix, $\frac{2}{3}$ lb of honey was added, and the resulting syrup was thoroughly mixed.

At the first trial this bait was poured into several containers and placed approximately 6 ft from the entrance of an average size wasp nest. Within 10 minutes worker wasps began feeding on the syrup. When inspected six days later the colony was virtually destroyed. When the nest was dug up the only live specimens found were 10 workers, several drones, and approximately 40 queens. All these were newly emerged individuals. All the poison bait had been consumed and hundreds of dead wasps were found in the nest entrance.

The same bait was later used in an orchard at Hillcrest where worker wasps were feeding on overripe apples. Their nest was approximately 300 yd away and, as was to be expected, only a small proportion of the field force was feeding in the orchard.

When bait was put out in shallow containers a few workers were immediately attracted to the syrup. The following day many dead wasps were found surrounding the baits, and it was reported that wasps were returning erratically to the nest, often falling down the bank where the nest was situated. The nest was later fumigated and dug up, but no irregularities were found. It would seem that the concentration of sodium arsenate was excessive as many wasps had obviously failed to return to the nest.

In the following autumn (10 March 1950) an extremely active nest of *V. germanica* was discovered at Hillcrest. The nest was more or less isolated and it was decided to observe the results of placing poison baits in the surrounding area. As the above bait was rather expensive and fermented molasses had been shown to be very attractive to worker wasps, a bait containing a 10 per cent solution of molasses plus yeast and 2 per cent sodium arsenate was substituted. Twelve tins containing this bait were hung in trees within a radius of 100 yd of the nest. Baits were renewed each week. Very few wasps were observed feeding on the molasses solution and no appreciable reduction in colony strength occurred, although the solution was shown to be toxic to the foraging workers.

When the experiment was repeated near an apiary that was being severely robbed by wasps similar results were obtained.

The failure of the latter tests to bring about any appreciable control is attributable to the fact that, unlike bees, each wasp works independently and does not communicate the discovery of a suitable food source (in this case bait) to the other members of the colony. Consequently it is not possible to attract workers in large numbers to a particular source of food. Therefore, for baiting to be successful, large numbers of bait containers would be required, which would make the method uneconomical.

ARTIFICIAL HONEYDEW

This approach, using a special form of poison bait, has already been discussed (p. 61).

It has the same limitations as have poison baits.

TRAPPING

See pp. 11 and 64.

There is probably less chance of obtaining successful control of wasps by trapping in the autumn than in the spring and early summer when it is remembered that an average nest may contain 5,000 workers. Obviously traps would have to be unusually efficient to obtain the desired control.

BIOLOGICAL CONTROL

As with many other insect migrants, *V. germanica* apparently arrived in New Zealand free of its natural parasites and predators and no signs of parasitisation have been found in any of the 300 nests that have been dug up and dissected.

In 1948 Dr Cumber of the Entomological Research Station, Nelson, was requested to investigate the possibilities of biological control of *V. germanica* in New Zealand. In a letter he supplied the following information:

> "Parasites of *Vespula* include—
>
> (a) *Metoecus paradoxus* L. Col. Rhipiphoridae.
>
> This parasite depends upon the chance transportation of the egg or larva by the returning wasps for its access to the nest. Where parasitisation occurs, this is of a very low degree, and no measure of control could be expected through this agent.
>
> (b) *Aphomia sociella* L. Lep. Galleriidae
>
> In England a small number of nests are destroyed annually by this moth. The larvae cover the nest with a silk webbing and destroy brood and nest material. Humble-bee nests are also destroyed by this moth.
>
> (c) Nematode worms
>
> Mr Ford, of Watkins and Doncaster, The Strand, London, mentioned in conversation that he had noticed nematode worms associated with and apparently parasitising wasp nests in England."

As none of these parasites seemed worthy of further consideration no action was taken.

Mr Albro T. Gaul, in a letter, kindly furnished the following data on a number of parasites that collectively keep the vespine population within reasonable bounds in New York and Massachusetts:

> "*Polistiphaga fulva* Cresson (= *Mesostenus arualis* Cresson) Ichneumonidae. Occurs largely on *Polistes*, but I have bred it artificially on *V. squamosa* Drury. Inhabits the wasps nest, deposits one or more eggs in each brood cell, perhaps polyembryonic. Parasitism effective after pupation. Ninety-nine per cent of parasitised wasps die. About 1 per cent survive and are sterile.

> *Sphecophaga burra* Cresson, Ichneumonidae. Endemic on North American vespines. Excellent parasite, with similar biology to the above, but almost completely specific to the sub-family Vespinae. Unfortunately this species is quite rare.
>
> *Melittobia chalybii* Ashmead, Chalcidae. Highly non-specific. It will attack almost any Hymenopherous larva or pupa while in a vespine colony it creates a rapid decimation of the populations. The life history is short: it is widespread in this country, it is small enough for easy transport to New Zealand by plane, it has been reported on other orders than the Hymenoptera but its favoured hosts are the social Hymenoptera. It is small enough to gain entrance to the nests. Here in this country I consider it a definite factor in the normal control of vespine populations. I have never heard of its affecting honeybees. It is more prolific in warm climates than in the northern areas here."

V. germanica Fab. is not present in North America but the two closely related species, *V. maculifrons* R. du Buysson and *V. vulgaris* L., are well established.

Although Mr Gaul considers *Melittobia chalybii* the most effective of the above parasites, the fact that it is highly non-specific detracts from its value.

Sphecophaga burra Cresson. is probably the most promising of the recorded parasites of *Vespula*, and if the decision is made to implement biological control in New Zealand this Ichneumon is worthy of careful consideration.

ACKNOWLEDGMENTS

In the course of the investigation much help was received from the Department of Agriculture, which also provided facilities for storage of equipment at Galloway Laboratory, Hamilton. Appreciation is recorded of the advice and assistance given and the interest taken in the work by Mr C. R. Patterson of the Horticulture Division of the above Department. His help was of great benefit to the investigation. Mr E. Hall of Hamilton also cooperated to the fullest extent. He was always ready to give his time and advice, and also permitted an insectary to be erected on his property. Messrs Slade and E. Wade allowed bait traps to be placed on their properties.

The writer is indebted to Miss J. Dingley, Plant Diseases Division, and to Botany Division, Department of Scientific and Industrial Research, for plant identifications; to the Commonwealth Institute of Entomology and Mr J. Bequaert, Museum of Comparative Zoology, Massachusetts, U.S.A., for identification of insect material; to Mr A. T. Gaul of New York who supplied most of the information regading parasites of *Vespula*; and to Mr J. A. Cederman, Orchard Instructor, Department of Agriculture, Kaikohe, who supplied the records from which the map shown in fig. 2 was compiled.

Special thanks are due to Dr W. Cottier, now Director, Entomology Division, Nelson, for supervising and assisting in the investigation, and to Mr S. A. Rumsey, Plant Diseases Division, for the many fine photographs.

SUMMARY

Although first recorded in New Zealand in 1922, the European wasp, *Vespula germanica*, did not become established in this country until 1945, when it was found breeding in the Hamilton district. Its annual spread was assisted by rail and road traffic until, in 1951, wasps were widespread over most of the North Island.

Trapping experiments carried out in 1949–51 with a variety of baits indicated that dilute beer was the best attractant tested. Workers were most abundant in late April and early May. Peak catches of drones were made in mid May, while queens were most abundant in late October.

During the active season marked changes in the diet of worker wasps occurred. Insects and other animal matter comprised the main food for workers in spring and early summer but in mid March there was a sudden change to a predominantly sweet diet. Honeydew of Homoptera, damaged fruit, jam, honey, and other sweet materials were then sought. Drones also preferred sweet materials and, in addition, both drones and workers imbibed oral secretions of larvae in their nest. Foraging workers imbibed large quantities of water and carried it back to the nest. Nests were seldom found more than 400–500 yd from a water supply. Queen wasps fed primarily on honeydew and on nectar as well.

After mating in the autumn queen wasps hibernated in sheltered situations. They did not forage after mating. Hibernation lasted until late August or early September when, with the onset of warm weather, the queens started to feed and commenced nest establishment. By midsummer nests were usually established. Subterranean sites were favoured, though (contrary to overseas findings) aerial sites were not uncommon. Details of nest construction are discussed.

When the first batch of workers reached maturity the queen ceased foraging and engaged solely in egg laying. The workers collected food and water and constructed and maintained the brood combs.

Drones emerged from mid February to late May or June, and were also sometimes found in overwintering nests throughout the year. Since drones did not forage until the end of the colony was approaching, extreme demands were made upon foraging workers at this time. It was then that wasps became pests because of their fondness for sweet materials. It is suggested that drone-producing eggs were laid by workers and not by the queen.

The change from drone to queen production was abrupt and appeared to be initiated (in part at least) by the first winter frosts. Mating usually occurred in late April or May when queens and drones were mature. Details of mating are described. After mating of the queens colonies declined, until by late May or June only the hibernating queens still survived.

Some unusually large nests have been found in this country and, indeed, the average nest size appears to be considerably larger than those described elsewhere. Over 11,900 adult wasps were counted in one large nest.

Where winter frosts did not occur many wasp nests overwintered. In these nests unused combs were sealed off and many cells were sealed with

paper discs. Brood production was much less than in summer nests and the majority of brood produced were queens. With the onset of warm, spring weather the production of the worker caste was resumed. Such nests may remain active for several seasons, and these (particularly aerial ones) sometimes attain enormous proportions.

The main economic damage caused by wasps was to fruit in orchards and vineyards and the robbing of honey stores from beehives. Losses of fruit were small since peak abundance of wasps did not occur until April or May, when most commercial fruit crops were already picked. Robbing of winter stores from beehives was sometimes serious, autumn-reared nuclei being especially liable to attack. On the other hand, wasps were beneficial in that they killed and ate many harmful insects, especially flies and caterpillars.

Control experiments aimed at (a) destruction of hibernating queens, (b) destruction of spring queens, and (c) destruction during the nesting phase. The first two proved impracticable since only a small proportion of queens need survive to maintain the population level. Chemical treatment of nests proved the most effective method of control. Several insecticides were effective, the most suitable for general use being 10 per cent DDT dust blown into the nest entrance, or chloropicrin as a fumigant. The use of poisonous sprays or baits on plants was complicated by their danger to foraging bees. Biological control is discussed.

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APPENDIX

TREATMENT OF NESTS FOR OBSERVATION

Once a subterranean nest has become established it is difficult to remove it to a cage for observation without destroying or losing the foraging workers.

However, Mr E. Hall has devised a method whereby the foraging members of a nest can be trapped and the nest dug up and transferred to a cage without the loss or destruction of a single individual, provided a little care is taken and a suitable trap is available.

The trap used for this purpose is shown in fig. 30, and consists of a reinforced gauze cylinder with a removable lid, preferably perforated by a $\frac{1}{2}$-in. hole in which a cork can be inserted. The bottom of the cylinder is a piece of galvanised iron soldered to the gauze above and having a hole of approximately 4 in. diameter cut in the centre. Over the hole and fixed to the galvanised iron bottom is a wire gauze cone perforated by a hole just large enough to allow a wasp to pass through. This whole cylinder is fixed to a galvanised iron base by three legs each approximately $\frac{3}{8}$ in. high.

This lower galvanised iron base is also perforated by a hole of approximately 4 in. diameter. A wire handle attached to the cylinder walls is an added advantage.

The trap, which is best operated on level ground during daylight, is placed directly over the entrance of the selected wasp nest. Special care should be taken so that the base of the trap is in contact with the ground, any irregularities in the surface being filled with soil.

Wasps leaving the nest will pass through the perforated gauze cone and become trapped in the gauze cylinder. By beating the ground above the nest most occupants of the nest can be driven out into the trap.

Worker wasps returning from the field finding the nest entrance blocked quickly investigate and soon find the gap between the two bases of galvanised iron. They then enter the nest but are driven out again by the periodic beating on the ground. In this manner the flying members of a nest can all be trapped in upwards of $1\frac{1}{2}$ hr. The trap can then be removed and the nest carefully dug up. Usually only the queen and a few newly-hatched individuals will be found in the nest, which can then be removed to a cage.

By removing the cork in the lid of the trap and placing the cage opening over the trap the workers will soon pass upwards into the cage, particularly if the trap is protected from the light.

The cage should be kept closed overnight and opened the following morning. After several exploratory flights the workers begin to forage normally, and although some may become lost, within a week the rapidly emerging adults soon build up the field force to such a stage that very little interruption of the activities of the colony occurs.

Quite large nests can be treated in this way, but the method is more applicable to young nests wanted for observation.

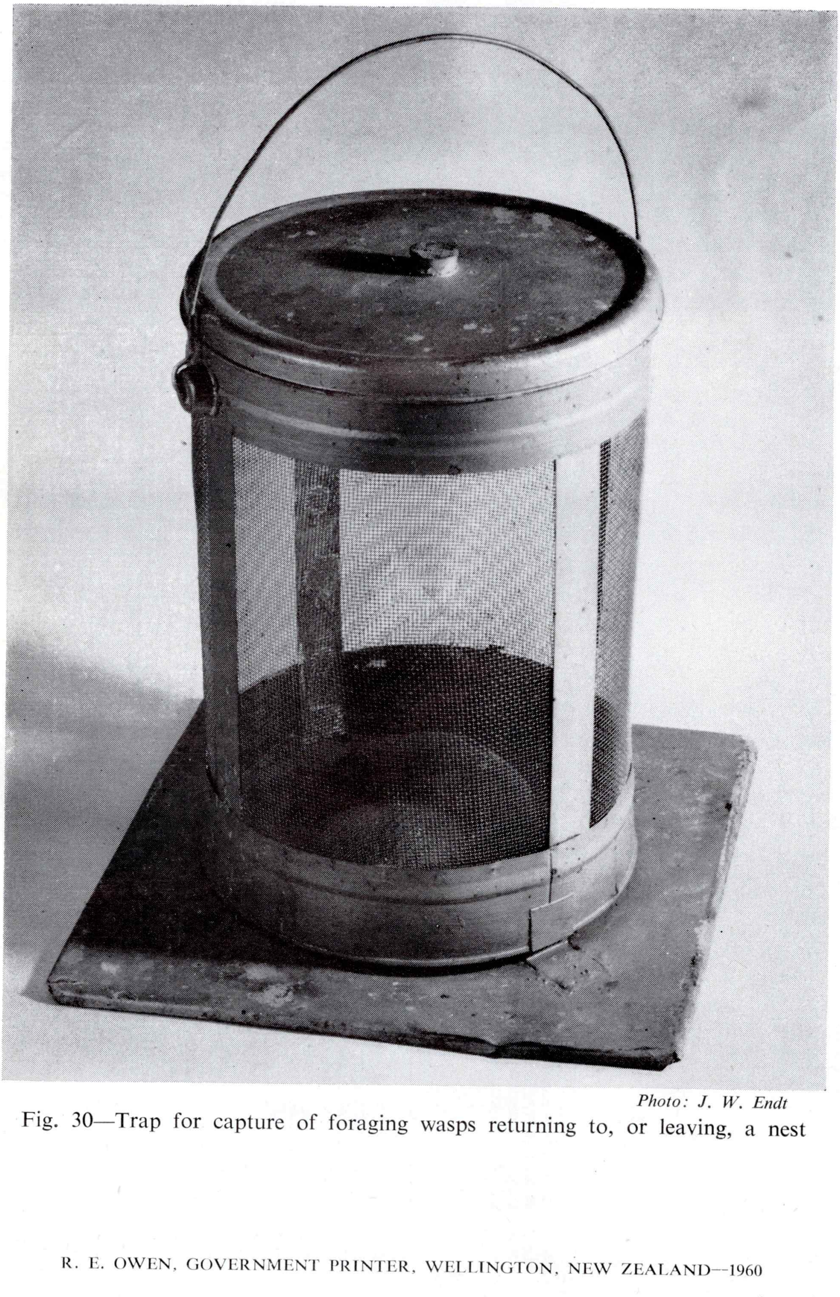

Photo: J. W. Endt

Fig. 30—Trap for capture of foraging wasps returning to, or leaving, a nest

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